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Pests of Stored grain and their Control

By

HEM SINGH PRUTHI & MOHAN SINGH

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COVER ILLUSTRATION

"BUKHARIS"

A type used in Bihar
for storage of grain

PESTS OF STORED GRAIN

AND

THEIR CONTROL

E.H.N.

BY

HEM SINGH PRUTHI, M.Sc., Ph.D. & Sc.D. (Cantab.), F.R.A.S.B., F.N.I., F.E.S.I.

Plant Protection Adviser to the Government of India

AND

MOHAN SINGH, M.Sc. (Hons.), F.E.S.I.

Storage Entomologist, Directorate of Plant Protection, Quarantine & Storage, Ministry of Agriculture, New Delhi

WITH A FOREWORD

By

THE HON'BLE SHRI JAIRAMDAS DAULATRAM,

Minister for Food and Agriculture

(THIRD REVISED EDITION)

सत्यमेव जयते

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FOREWORD

FOODGRAINS have necessarily to be stored after harvesting for shorter or longer intervals either for future consumption or for the purpose of seed for the next cropping season. It is essential that during the period of storage foodgrains should not suffer any deterioration either in quantity or in quality. Our worst enemies in this respect are a host of pests, especially insects, which attack stored grain and consume them or otherwise affect their value either as food or as seed. Stored foodgrains should be afforded all possible protection from agencies which destroy them or diminish their possibilities of utilization. In view of the prevailing food shortage it should be our duty to ensure that not even a grain goes waste. Those of us who are concerned in the production and distribution of foodgrains have a special responsibility in this connection.

The population and food supply of a country are directly related ; the larger the population, the greater should be the food supply. It is obvious that food production in this country has lagged behind the growth of population. As a result of this persistent shortage, a large section of the population suffers from malnutrition and from year to year food has to be imported from outside to cover the deficit. India can ill-afford to put up with the economic drain which this import inevitably entails.

While increased production at home is a proper means of improving the situation, prevention of any waste of foodgrains produced at present is no less important. Whatever is the progress made in the matter of food production, food which is already available with us must be conserved so as to reduce the extent of the shortage.

The extent of the loss which results from the ravages of various pests is generally not appreciated to the extent it should be. It has been estimated that the loss thus brought about is about 5 per cent of the total foodgrains stored, i.e. about 2·5 million tons. The Rice weevil alone causes a loss of stored wheat in this country valued at nearly a crore of rupees a year. It is apparent that this loss adversely affects the national economy of our country and, as such, its prevention is to be looked upon as a question of country-wide importance and of immediate urgency and is not to be tackled only as a problem of scientific curiosity.

The storage of grains is not a new innovation introduced into this country. Storage of grains on a large scale has always been practised in some form or other in this country from times immemorial. But the older methods of storage have probably to be adapted to, or readjusted in accordance with changed circumstances. With the increase of scientific knowledge and technique and better knowledge of the life-history and habits of the pests it may now be possible to store grains by other methods so as to render them to a great extent impervious to pest attack.

Dr Hem Singh Pruthi and Sardar Mohan Singh have produced a work on 'Pests of Stored Grain and their Control' which gives a detailed survey of different kinds of pests and suggests methods of storage by which grains can be saved from their attack. It is hoped that the publication in the present revised and enlarged edition will be found to be of considerable interest to all who are concerned with the storage, movement and distribution of food-grains.

Dated the 21st June, 1948

JAIRAMDAS DAULATRAM,

Minister for Food and Agricultur.

PREFACE TO THE THIRD REVISED EDITION

THE second edition of the Bulletin on Pests of Stored grains, etc. which was published in 1945 (*I.C.A.R. Miscellaneous Bulletin* No. 57) got exhausted in about 18 months' time because of the great interest evinced by entomologists, Civil Supply Officers and general public in this important subject. Moreover, since that year considerable amount of fresh knowledge about storage pests and methods of their control is available from various parts of the world. In the middle of 1947 an International Conference on Infestation of Foodstuffs organized by the Food and Agricultural Organization of the United Nations was held in London to take stock of the position and make recommendations as to the best methods of control under different conditions. One of us (Hem Singh Pruthi) led the Indian delegation to this Conference. The present edition has been thoroughly revised keeping in view the latest developments in this science. Special attention has been given to the use of new insecticides such as dichlorodiphenyl-trichloroethane (D D T) and benzene hexachloride products in connection with grain preservation. Sections dealing with rats and termites have also been written in some detail. Moisture plays an extremely important part in storage. The quantity of moisture in the grain and the store greatly determines whether the stock will remain safe or deteriorate in a short time leading to 'heating' and development of moulds, etc. Special attention has been given to this section also.

NEW DELHI

December, 3, 1948

HEM SINGH PRUTHI

MOHAN SINGH

I. GENERAL ACCOUNT OF IMPORTANT STORE PESTS*

(i) Pests of cereals

Sitophilus oryza Linn. (Plate I)

THIS pest is popularly known as the Rice weevil because it was first discovered breeding in rice. It was specifically named as *Calandra oryzae* as far back as 1763. At present it is perhaps the most widely distributed of known insects being found in all parts of the world. It is particularly common in warm countries. Some workers [Fletcher, 1911 ; Newman, 1927 ; Zacher, 1937] consider India to be the native land of this weevil, while according to others some temperate country is its original home.

It is a serious pest of paddy and almost all cereals and their products in India. In fact, it is the commonest pest that one encounters in all kinds of stores. It is known to attack the cereal crops especially wheat and paddy in some other parts of the world. In India, it is only on rare occasions that it has been noted infesting ripe grains in the field [Fletcher, 1914]. It has been found to prefer temperate but humid climates, but it continues breeding where it finds undisturbed conditions of storage.

Sitophilus oryza is a tiny weevil (1·6 in. long) with its head produced into a snout-like projection. At the end of this projection there is a pair of strong jaws. It is generally reddish-brown in colour but sometimes it is dark brown or almost black. There are light reddish or yellowish spots on the back. The two sexes look superficially alike but when carefully examined, the males can be distinguished from the females by the form of the rostrum which is shorter and broader in the male than in the female.

Life-history and habits

Both adults and larvae attack the grain upon which they feed voraciously so much so that the grain is rendered unfit not only for human consumption but for seed purposes also. In cases or heavy infestation the grain becomes a mass of broken vegetable matter.

The adults make small excavations in the soft part of the grain where they lay eggs. Frequently numerous such excavations are seen on the same grain which indicates that the mother weevil carefully selects the site which is fit for maintaining larval life. The egg is oval in outline but being somewhat elastic can conform to the shape of the cavity. It is placed with the top just below the surface of the kernel, with the larger end towards the bottom of the cavity.

A single female can lay as many as 250 eggs. In Australia there is a record of 400 eggs per female. The egg is translucent and white in colour. It measures 0·7 mm. long and 0·3 mm. broad. Therefore, such tiny eggs are liable to be overlooked and missed unless carefully examined by trained eyes. Under optimum conditions it hatches in about four days' time during summer (August and September) but may take six to nine days during winter.

The young tiny grub bores into the grain kernel. The grub is white, with yellow brown head and biting jaws and lives within the grain feeding on its starchy contents and hollowing it out leaving only a shell intact, till it becomes a full grown larva. As the grub feeds and moves along, the frass is kept packed behind. The space round the grub is clear and is slightly larger than the size of grub so that the latter can readily turn round. If disturbed, the grub turns its head towards the side of attack gnashing its mandible. As a rule only one grub is found inside one grain but there may be two to three depending on the size of the kernel. The grub stage lasts from 19 to 34 days.

The full grown grub makes a pupal cell inside the grain and pupates after passing one or two days as a prepupa. It becomes sluggish, lengthens out, losing its humpy appearance. The pupal stage lasts from three to six days depending on the prevailing temperature, but sometimes to as long as 20 days.

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* A complete list of important pests is given as appendix at the end of this paper on p. 76.

The adult weevils emerging out of the grains are at once ready for breeding and giving rise to a new generation to carry on the work of destruction. As will be obvious from above, the durations of various stages in the life-cycle of the weevil and the number of its generations in a year vary with the prevailing temperature and humidity conditions. The size of the weevil generally depends on the size of the grain in which it breeds, the individual breeding in small grain is usually smaller than that breeding in large grain such as maize.

There are generally five generations in a year but seven or eight are also on record in countries having equable climatic conditions. In India, there are four or five generations ; the first three are generally passed in quick succession each occupying a period of about a month. On an average the period from the egg to adult is completed in one month during warm months and in two to three months under adverse conditions. The duration of the adult stage depends on a number of factors. Those adults that emerge during spring and summer months have an average length of life from three to six weeks. These weevils mate immediately after emergence and start laying eggs. Among weevils which emerge in winter months, mating and oviposition are less frequent ; therefore they do not get exhausted by egg-laying and their life period is consequently prolonged. The greatest amount of damage by the weevil is, therefore, done between August and November, comparatively less in February and March and least in December-January and during very hot months. It has been seen that one pair of weevils may give rise to a progeny of one million individuals in a single season of three months.

Natural enemies

Aplastomorpha calandrae How. is the chief parasite of the grub. This parasite does not become common until the grain is very heavily infested and the damage has reached its peak. The possibility of control of the weevil by this parasite offers little prospects of success. The Chalcid, *Lariophagus distinguendus* Forst., is another common parasite and the mite, *Pediculoides ventricosus* Newport, is predaceous on the grubs.

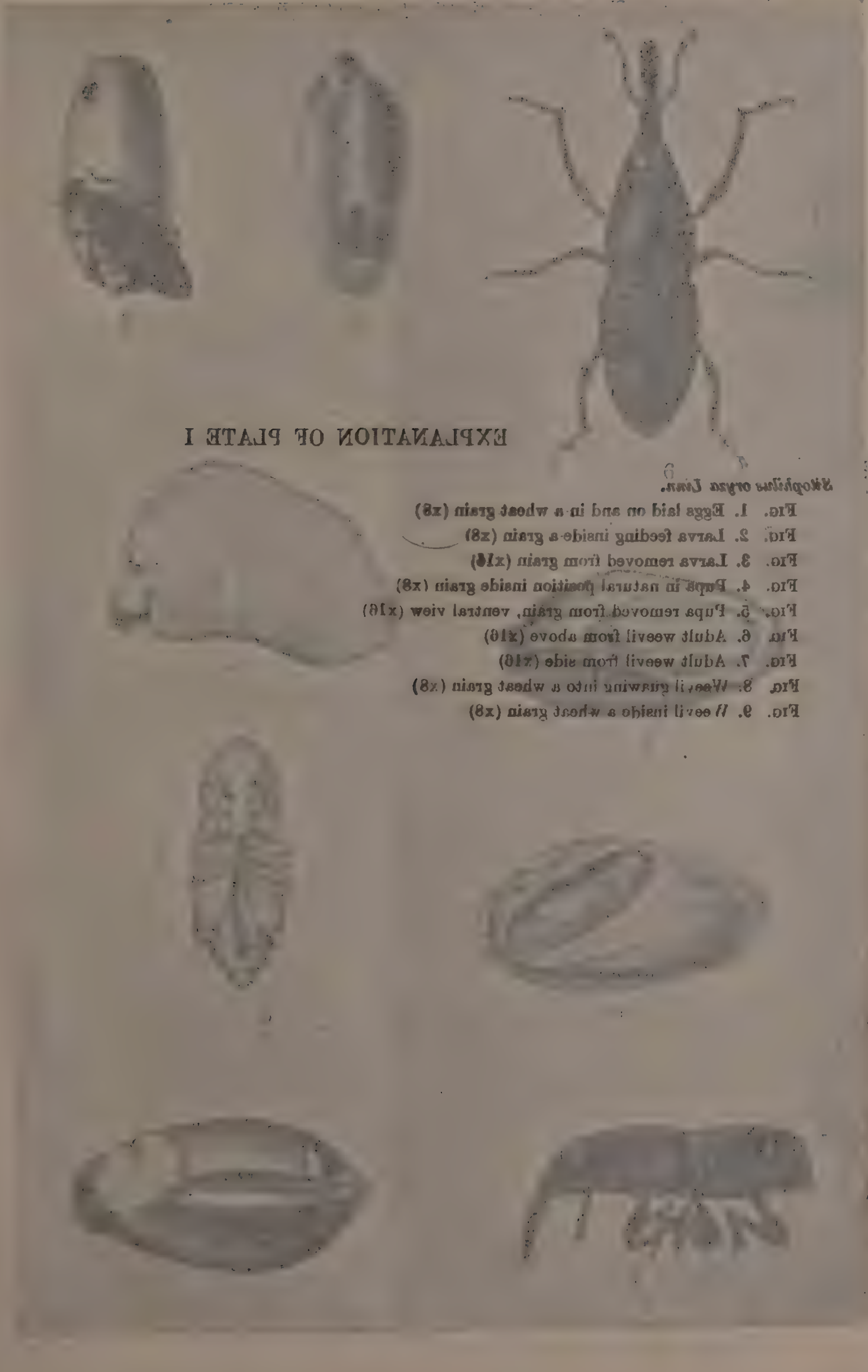
Sitophilus granarius Linn.

This insect is allied to the Rice weevil and is popularly known as the Grain weevil or Granary weevil. This weevil was described as *Calandra granaria* nearly 200 years ago. It is one of the oldest known insect pests and is almost cosmopolitan in distribution, having been carried by commerce to all parts of the world. In general habits and biology (life-history), the two weevils are very similar. The Grain weevil differs from the Rice weevil chiefly in being larger, uniformly brown with polished elytra and larger punctures on the thorax and having wings obsolete.

The Granary weevil is of considerably less importance in India and other hot countries than in Europe.

Rhizopertha dominica Fab. (Plate II)

Rhizopertha dominica can be classed as second in importance to *Sitophilus oryza* as a destroyer of stored grain. This pest is popularly known as the Lesser grain borer or Australian wheat weevil. It was descrided in 1792 from specimens from South America The original home of *R. dominica* is not known for certain but general opinion is that it is India or the Indian sub-region. In fact, this area is also considered to be the place of a large number of other species of Bostrychidae. Besides India, in numerous other parts of the world, e.g. Argentina, the United States and New South Wales, *R. dominica* constitutes a major pest of stored grain.



EXPLANATION OF PLATE I

Sitophilus oryza Linn.

FIG. 1. Eggs laid on and in a wheat grain (x8)
FIG. 2. Larva feeding inside a grain (x8)
FIG. 3. Larva removed from grain (x16)
FIG. 4. Pupa in natural position inside grain (x8)
FIG. 5. Pupa removed from grain, ventral view (x16)
FIG. 6. Adult weevil from above (x16)
FIG. 7. Adult weevil from side (x16)
FIG. 8. Weevil gnawing into a wheat grain (x8)
FIG. 9. Weevil inside a wheat grain (x8)


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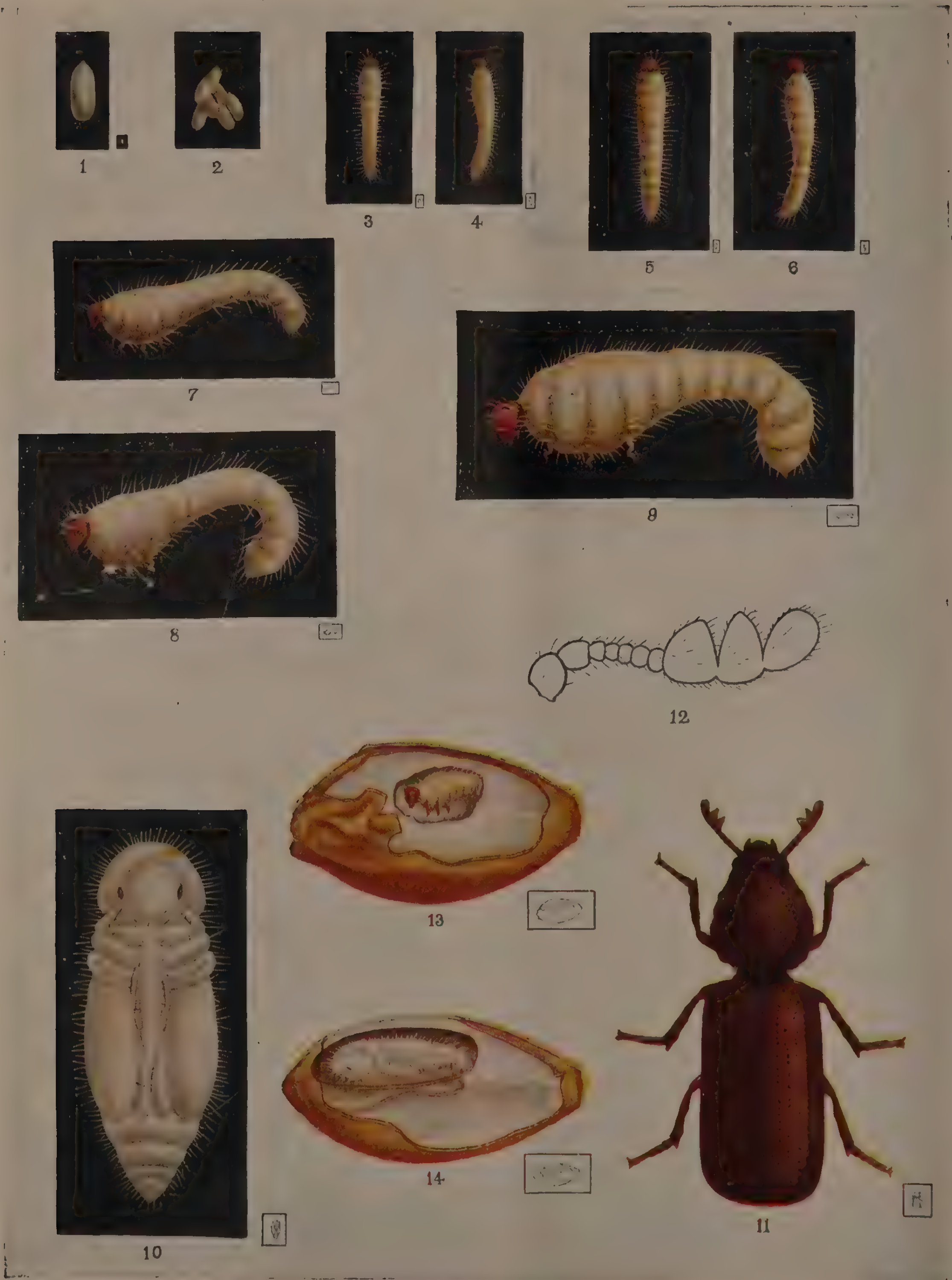
PLATE II



EXPLANATION OF PLATE II

***Rhizopertha dominica* Feb.**

- Fig. 1. The egg (x20)
- Fig. 2. A cluster of eggs (x10)
- Fig. 3. A freshly emerged larva, dorsal view (x26)
- Fig. 4. A freshly emerged larva, lateral view (x26)
- Fig. 5. The larva after the first moult, dorsal view (x26)
- Fig. 6. The larva after the first moult, lateral view (x26)
- Fig. 7. The larva after the second moult (x26)
- Fig. 8. The larva after the third moult (x26)
- Fig. 9. The fully developed larva just previous to pupating (x20)
- Fig. 10. The pupa, ventral view (x20)
- Fig. 11. The adult showing the attitude when actively moving about (x20)
- Fig. 12. An antenna
- Fig. 13. A grain showing the larva inside (x6)
- Fig. 14. A grain showing the pupa in the cavity excavated by the larva (x6)

The small figures by the side of the larger ones indicate the natural size of the different stages of the insect

Trogoderma granaria Everts. (Plate III)

PLATE II

R. dominica belongs to that group of insects which bore into wood in both adult and larval stages. This species was at one time often found in the wood used in packing cases. It has now been recorded from cereals, grocery and drug stores and on various types of grain and dried fruits. Now, it is a major pest of nearly all cereals. Grain heavily attacked by this pest may be hollowed out until only a thin shell remains. As many as four beetles may be found in a single grain such as maize because of the bigger size of the grain. This beetle has been often found breeding in flour and ' maida '. Dean [1947] has recorded its attack on wheat in the field.

It has sometimes been found that the beetle larvae are unable to attack sound grain [Potter, 1935]. What happens is that the female lays eggs not only on grain but also in other parts of the store, on bags, walls, among the food materials remaining in crevices, etc. The larvae hatching from the eggs laid on grain bore straight into the grain and pass their entire life in the grain. Larvae which hatch out of eggs laid in other parts of the godowns go about feeding on farinaceous material lying about the store. The first stage larvae, being straight in outline, can bore into sound grain, but possibly not the second stage ones ; in the later stages of growth the curved shape of the larvae perhaps makes it difficult for them to penetrate the grain.

R. dominica can be distinguished from other store pests by its cylindrical shape and small size ($\frac{1}{8}$ in. $\times \frac{1}{32}$ in.). It is polished dark brown or black in colour with a somewhat roughened surface. Its head is inverted into a hood-like triangular structure under the thorax. The species possesses powerful jaws with which it causes serious damage to the grain and any part of the wooden structure in the store or warehouse to tide over an unfavourable period.

Life-history and habits

The female generally lays eggs on the grain near the embryo-end, which is comparatively soft and from where the young larvae easily enter the grain. As stated above, eggs may also be laid on walls, bags, and in cracks, etc. A single female may lay 300 to 500 eggs. Eggs are pear-shaped, glistening white when freshly laid, but they become pinkishly opaque as the larvae develop inside the egg-shell. The duration of the egg stage is five to six days during summer, 7 to 11 days during autumn and much longer in winter.

The newly hatched larva is quite active. It is campodeiform in shape. It burrows at once into the grain or crawls actively about, feeding on the loose starchy material in the store. The larva undergoes four or five moults [Lesne, 1924], but its life-history inside the grain has not been worked out in detail. There may be even three moults. The full-grown larva is dirty white with a light brown head and curved abdomen. It is covered with tiny hairs. On an average the larval period is about 44 days. It is difficult to distinguish the two sexes in the larval stage but sexual dimorphism is evident in the pupal stage. The prepupal and pupal periods last for seven to eight days. The total life cycle from egg up to the emergence of the adult is about two months. There are generally five generations in a year.

R. dominica does not flourish in grain infested with fungi. Predaceous mites, such as *Pediculoides* spp. have been reported to attack eggs and larvae of *R. dominica* and seriously reduce their number or even entirely destroy them ; but conditions required for the existence of these mites in large numbers, however, are such that they are not likely to be serious enemies of the beetle [Goodrich, 1921]. Hymenopterous parasites of *R. dominica* have not been fully studied. Goodrich [1921] recorded the Chalcid parasite, *Lariophagus distinguendus* Forst., attacking the larvae and rarely also the pupae.

Trogoderma granaria Everts. (Plate III)

This pest, commonly known as 'khapra' is cosmopolitan in distribution. It feeds on wheat of which it is the major pest. Oats, rice, 'jowar', maize are also eaten well and it generally thrives in places where the prevailing temperature is between 90°F. and 110°F. During the present emergency when the Punjab wheat has gone to every part of India, 'khapra' has established itself in places where

there was no record of this pest before. Generally speaking the infestation occurs in superficial layers of grain as the pest is not able to penetrate beyond some depth into the grain. In cases of very heavy infestations, *T. granaria* has been seen to affect the whole lot. The damage to grain is done by the larvae while the adult is harmless. They are most active from July to October when the heaviest damage is caused. As a rule they attack the embryo point but in cases of heavy infestation other parts of the grain may also be attacked.

The adult is about $\frac{1}{10}$ in. long, and almost oval in outline ; it has grey and light brown markings and emarginate eyes. The male is smaller and darker than the female.

Life-history and habits

The adults appear late in spring. The female starts laying eggs 5 to 6 days after mating which may take place immediately after emergence. The eggs are generally laid among the grain, sometimes as many as 26 per day ; a single female during her life-time can lay about 125 eggs.

The eggs hatch in 6 to 16 days depending on the prevailing temperature and humidity. In humid atmosphere the incubation period is five to nine days only.

The larva is brownish-white in colour, with the body covered with bundles of long, reddish-brown, movable and erectile hair on the posterior segments and forming a sort of tail at the posterior end. The young larva feeds on the floury debris resulting from the feeding of the older larvae, because it cannot attack the entire grain.

The larval period varies considerably. Under favourable conditions the male larva moults four times and the larval period is completed in about 50 days, but the number of moults may be doubled and the life cycle prolonged over a period ranging from 200 days to nearly four years under adverse conditions of temperature and humidity. During winter or in the absence of food the larvae are inactive and live in cracks and crevices and any concealed places behind wall plasters and in the seams and meshes of bags.

The pupal stage lasts 6 to 17 days. The adults are ready for egg-laying in two to three days after emergence and live 10 to 32 days after reaching maturity.

Tribolium castaneum Herbst. (Plate IV, figs. 1-5)

This species was described in 1797 and is popularly known as the Rust-red flour beetle. The adult is a small, $\frac{1}{8}$ in. long, flattened and reddish-brown insect. The head, thorax and abdomen are distinct and the antennae are well developed, the last few segments being abruptly much larger than the preceding ones. It is a pest of stored grain and other products throughout the world found in granaries, mills, warehouses, etc. It is well distributed in all parts of India.

This pest does not do so much damage as *Sitophilus*, *Rhizopertha* and others in whose company it is mostly found. Neither the larva nor the adult can generally damage sound grains, but they feed on those grains only which have already been damaged by other insect pests. This pest has also been observed to attack the germ part of the sound grain, starting its attack from small lesions in the grain. Naturally, therefore, this is a serious pest of prepared cereal products such as, *atta*, *maida* and *suji* and is found in abundance in flour mills, etc. In cases of heavy infestation, flour or *maida* turns greyish yellow and subsequently becomes mouldy and emits pungent smell.

Life-history and habits

Eggs are laid singly and freely in flour, etc. and as they are rather moist and sticky when freshly laid, they soon become covered with small particles of dust and flour, etc. This renders their detection very difficult. A single female lays on an average about 450 eggs. The egg is small, slender, cylindrical in shape, rounded at both ends and of whitish colour. The incubation period varies from 5 to 12 days depending on temperature. A temperature of about 27°C. has been observed to be the most favourable for its development.

EXPLANATION OF PLATE III

Trogoderma granaria Everts.

FIG. 1. The egg (x13)

FIG. 2. A group of eggs showing the way they are sometimes laid together (x6)

FIG. 3. An egg a few days' old showing signs of the developing larva inside (x13)

FIG. 4. A freshly emerged larva (x26)

FIG. 5. The larva after the first moult (x26)

FIG. 6. The larva after the second moult (x26)

FIG. 7. The larva after the third moult (x23)

FIG. 8. The larva after the fourth moult (x23)

FIG. 9. The terminal segments of a larva after the fifth moult (x23)

FIG. 10. The pupa of a male beetle still enclosed in the last larval skin, dorsal view (x13)

FIG. 11. The pupa of a female beetle as in Fig. 10 (x13)

FIG. 12. The female pupa removed from the larva skin, ventral view (x13)

FIG. 13. *T. granaria* female (x13)

FIG. 14. *T. granaria* male (x13)

FIG. 15. Antenna of male beetle

FIG. 16. Antenna of female beetle

FIG. 17. A larva attacking a wheat grain

The small figures by the side of the larger ones indicate the natural sizes of the different stages of the insect

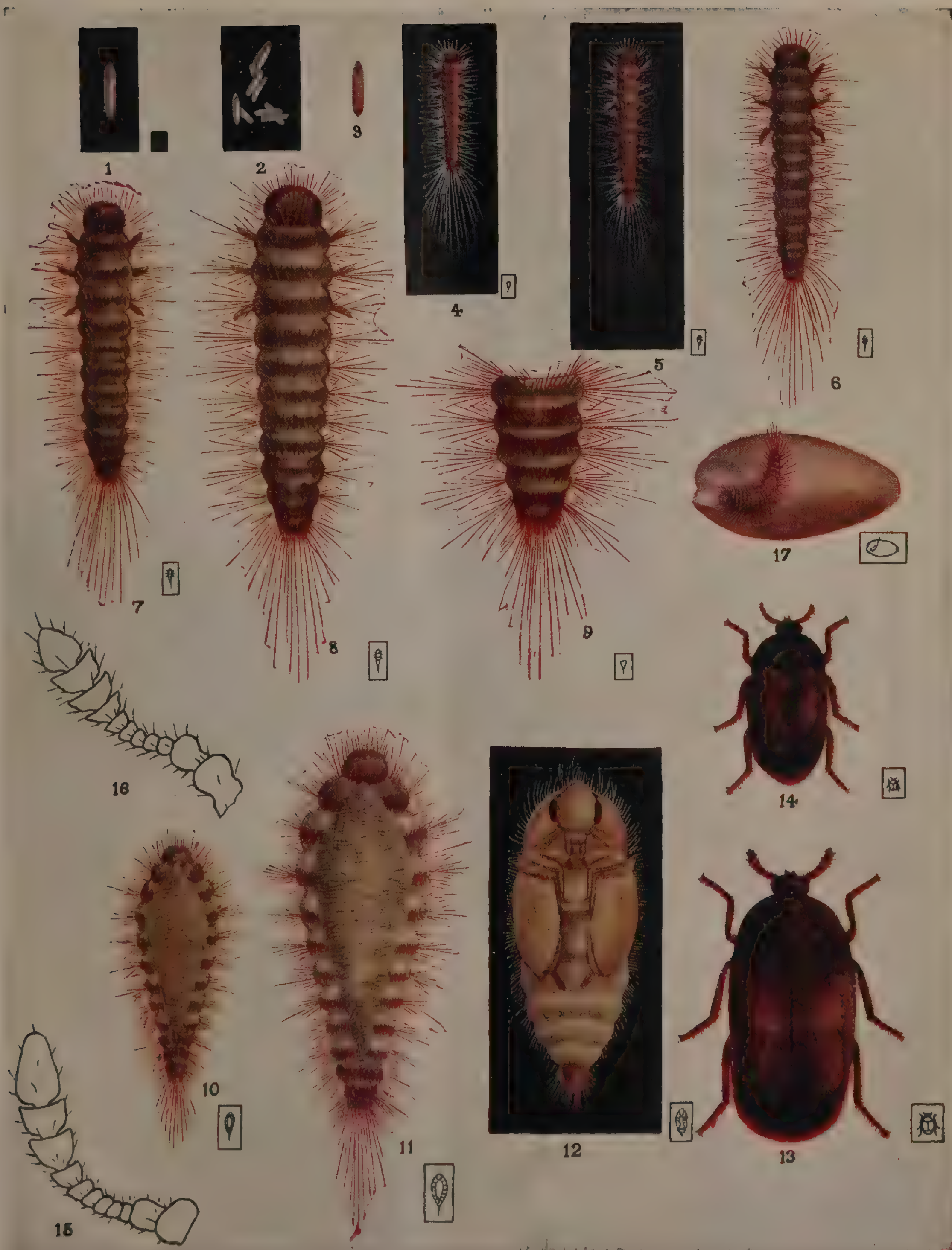

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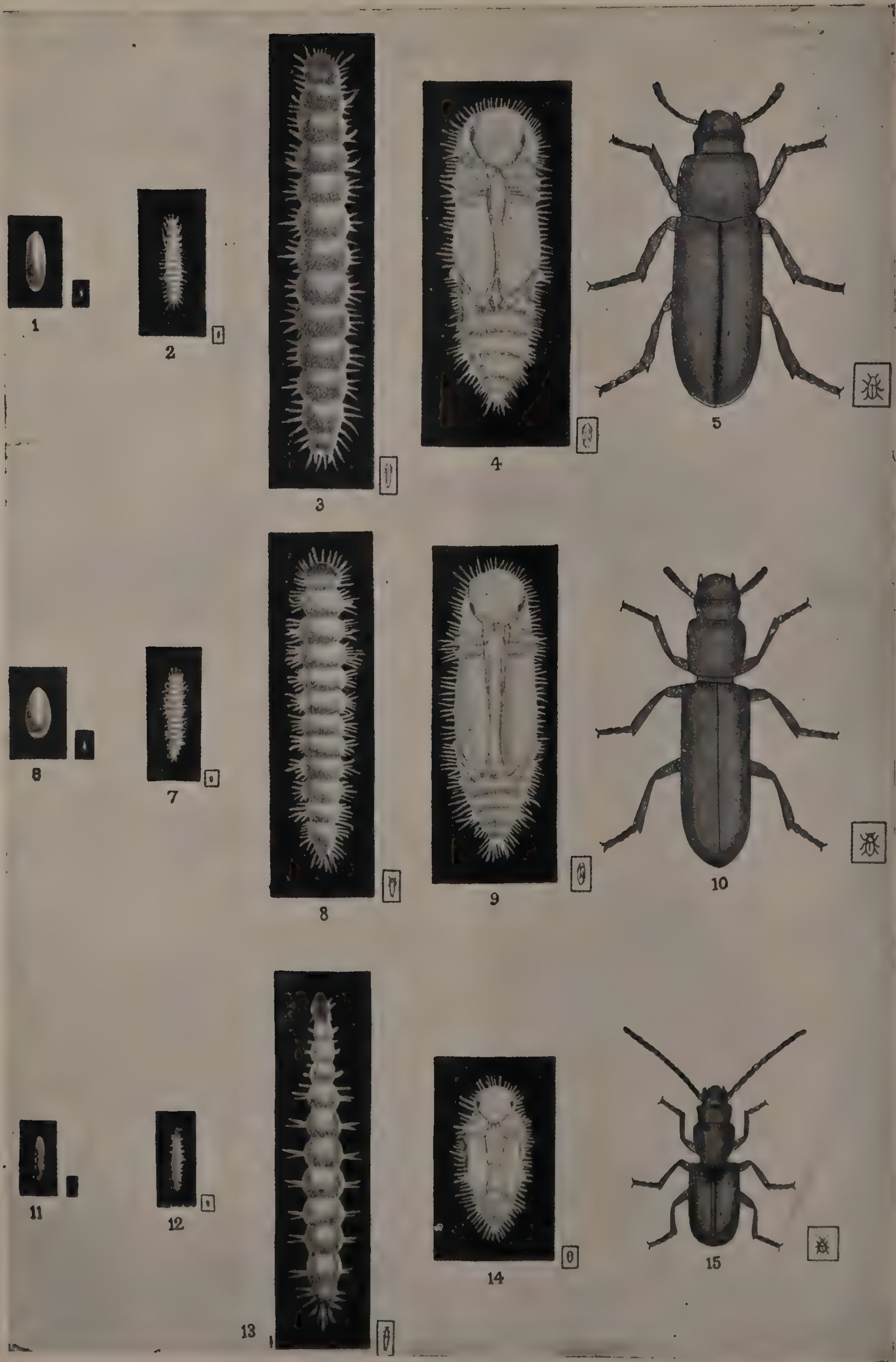
PLATE IV



those of the grub. Pupal stage lasts for 6 to 9 days.

and September, but is greatly prolonged in the cold weather.

Tribolium confusum Jacq. Duv.

EXPLANATION OF PLATE IV

Tribolium castaneum Herbst.

FIG. 1. The egg (x13)

FIG. 2. The freshly emerged larva (x13)

FIG. 3. The fully grown larva (x10)

FIG. 4. The pupa, ventral view (x13)

FIG. 5. The adult (x13)

Latheticus oryzae Waterh.

FIG. 6. The egg (x13)

FIG. 7. The freshly emerged larva (x13)

FIG. 8. The fully grown larva (x10)

FIG. 9. The pupa, ventral view (x13)

FIG. 10. The adult (x13)

Laemophloeus sp.

FIG. 11. The egg (x13)

FIG. 12. The freshly emerged larva (x13)

FIG. 13. The fully grown larva (x13)

FIG. 14. The pupa, ventral view (x13)

FIG. 15. The adult (x13)

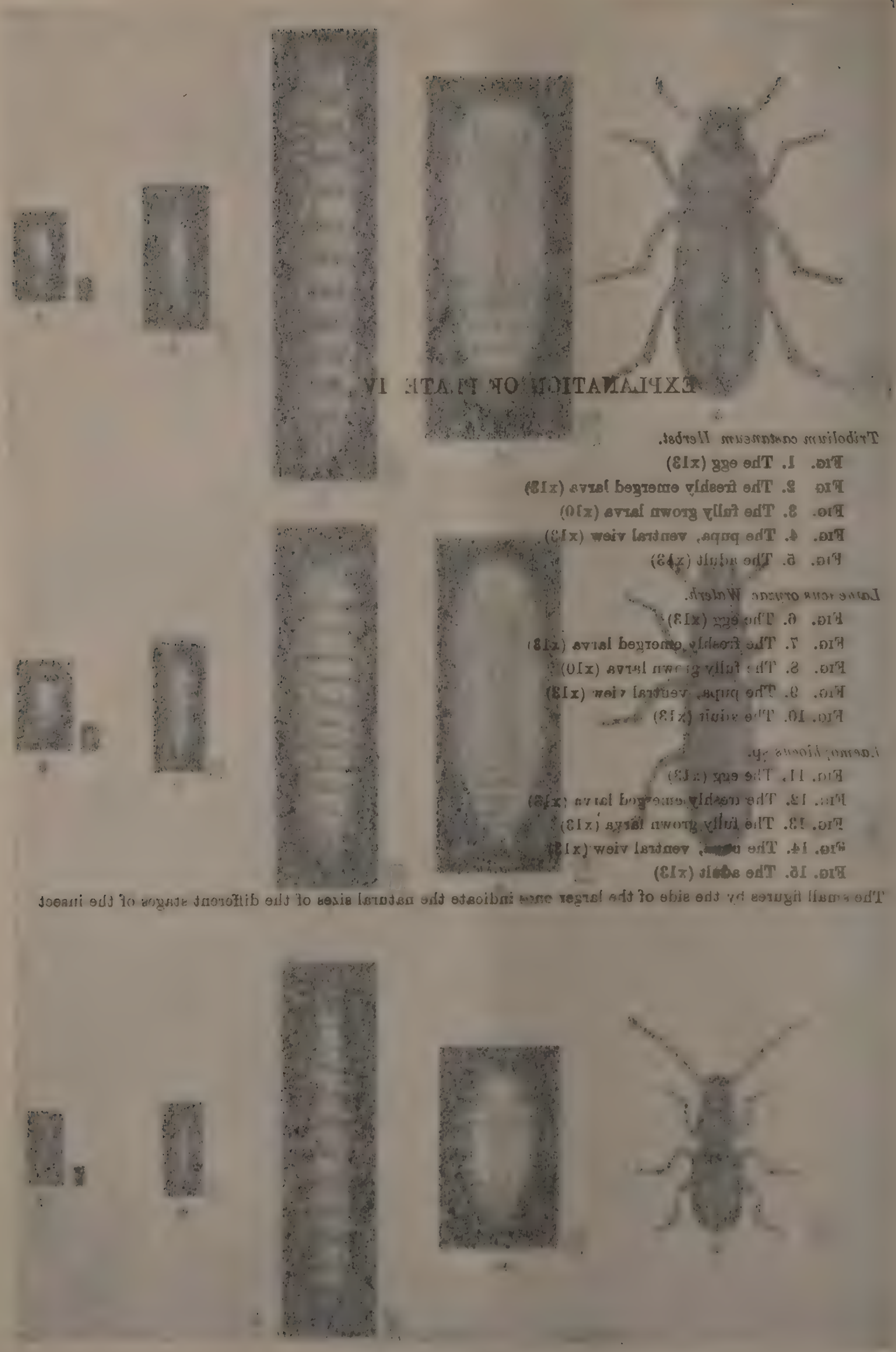
The small figures by the side of the larger ones indicate the natural sizes of the different stages of the insect

39 days depending on temperature and humidity.

Attagenus piceus Oliv. (Fig. A.)

Punjab as breeding in wheat chaff.

PLATE IV



The grub is small, worm-like, slender, cylindrical and wiry in appearance. The body segments have a number of fine hairs, the terminal segment being in addition furnished with a pair of spine-like appendages. The full-grown grub is about $\frac{3}{16}$ in. long and is pale yellowish in colour. The larval period varies from 27 to 90 days, according to the food available and the prevailing temperature. Pupation takes place generally on the surface of the food. The pupa is naked. At first it is white but gradually becomes yellowish, the dorsal surface having hairs and processes resembling those of the grub. Pupal stage lasts for 6 to 9 days.

The total life cycle from egg up to the emergence of adult lasts about six weeks during August and September, but is greatly prolonged in the cold weather.

Tribolium confusum Jacq. Duv.

This is commonly known as the Confused flour beetle because of its being confused for a long time with its closely allied species, *Tribolium castaneum.* It was originally described in 1868. It is a tiny reddish-brown insect, almost similar in appearance and habits to the preceding species, with the difference that its head and thorax are covered with minute punctures and eyes are lobed and folded. It occurs everywhere in company with *T. castaneum* and the life-history of the two species is almost similar.

Latheticus oryzae Waterh. (Plate IV, figs. 6-10)

The pest is popularly known as the Long-headed flour beetle. It is very closely allied to *Tribolium castaneum.* It has been reported that this beetle is almost always found along with *T. castaneum, Laemophlœus minutus, Oryzæphilus surinamensis.* This has been the reason that there is very little information regarding the occurrence and status of this pest in India though it was first recorded in 1880 as infesting rice in Calcutta. It is cosmopolitan in distribution and occurs freely in wheat stores. It also feeds on dried vegetable material of any kind, flour and meal, rye, etc.

The adult is slender, flattened, $\frac{1}{8}$ in. long, very much like *Tribolium confusum* in form, but smaller in size and, pale-yellow instead of reddish brown in colour. Its antennae are also somewhat club-shaped and slightly smaller than *T. castaneum.*

Life-history and habits

Very little is known about the life-history of the insect, but in main features it is similar to that of *T. castaneum.* The egg is cylindrical in shape, opaque with a smooth surface. The freshly emerged larva is very similar to that of *T. castaneum.* It is yellowish white with dark head and legs. Full-grown larva is distinguishable from that of *T. castaneum* being slightly short and light in colour. Body is covered with numerous light-coloured hairs. Spine-like appendages on the last segment are different from those on the larvae of *T. castaneum* and also lighter in colour. Pupa is slender and the various parts of its body are not well differentiated. Its life-cycle is completed in 25 to 39 days depending on temperature and humidity.

Attagenus piceus Oliv. (Fig. A.)

This cosmopolitan insect is popularly known as the Black carpet beetle. It is a pest of carpets and other woollen materials, but it is also found infesting grain and cereals. It was described in 1790 from Paris and is believed to be a native of Europe. In India it was originally reported from the Punjab as breeding in wheat chaff.

Life-history and habits

Attagenus piceus is a small oval insect about $\frac{1}{8}$ in. long. The head and thorax are black reddish-brown and clothed with short hairs. The legs and antennae are dark yellow.

It is usually found in association with other grain pests. It readily feeds on grains, but since it cannot thrive on a purely vegetable material, it supplements its diet by occasionally feeding on dead bodies of other grain pests. The beetles prefer dry and dusty places and are commonly found in crevices in the floors of silk factories. On the whole, *Attagenus piceus* cannot be considered as a serious pest of stored grain.

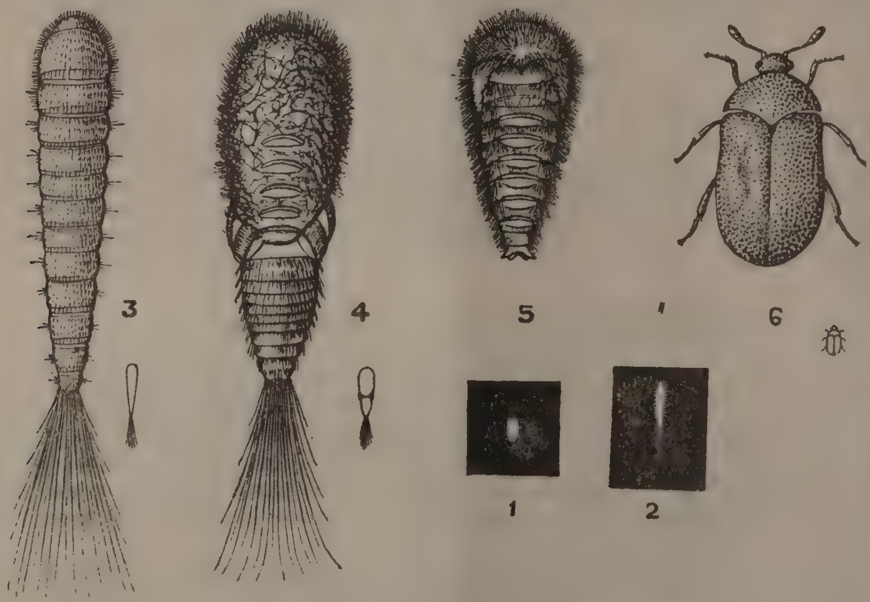


FIG. A. *Attagenus piceus*: 1. egg; 2. newly hatched larva; 3. full-grown larva; 4. prepupa; 5. pupa; 6. adult (×7). Smaller outline figures show the natural size

Under favourable conditions, a single female lays about 150 eggs. They are deposited loosely among foodstuff. The oviposition begins about 3 days after emergence. The eggs generally hatch in 6 to 9 days, but sometimes in 12 to 16 days.

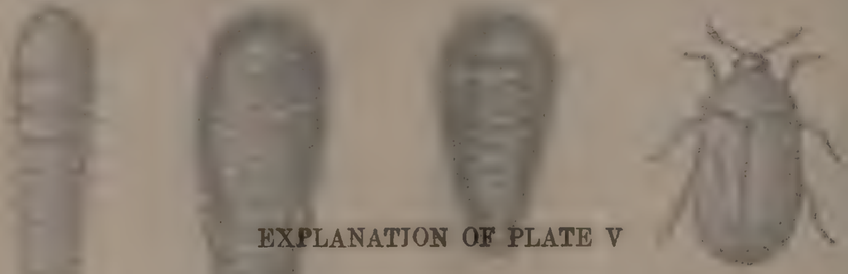
The larva is very characteristic and can be readily recognized. It is reddish-brown in colour, clothed with short, scale-like appressed hairs and provided with a tuft of long hairs at the posterior end of the body. The grubs of the same brood may remain in the larval stage for 1 to 3 years. The pupal stage lasts only for about a week.

Oryzaephilus surinamensis Linn. (Plate V, figs. 10-12)

This was described in 1767 from specimens from Surinam, hence the specific name. This pest is usually called the Saw-toothed grain beetle because of the fact that it has a row of small, sharp, saw-like teeth along each side of its thorax.

This pest is also cosmopolitan in distribution and is found all over India in almost any stored food of vegetable origin, e.g. flour, 'maida', biscuits, raisins, etc. The loss caused by this beetle is considerable although its attack usually follows that of other insect pests such as *Sitophilus*

Life-history and habits



EXPLANATION OF PLATE V

GRANARY AND HOUSE-HOLD PESTS

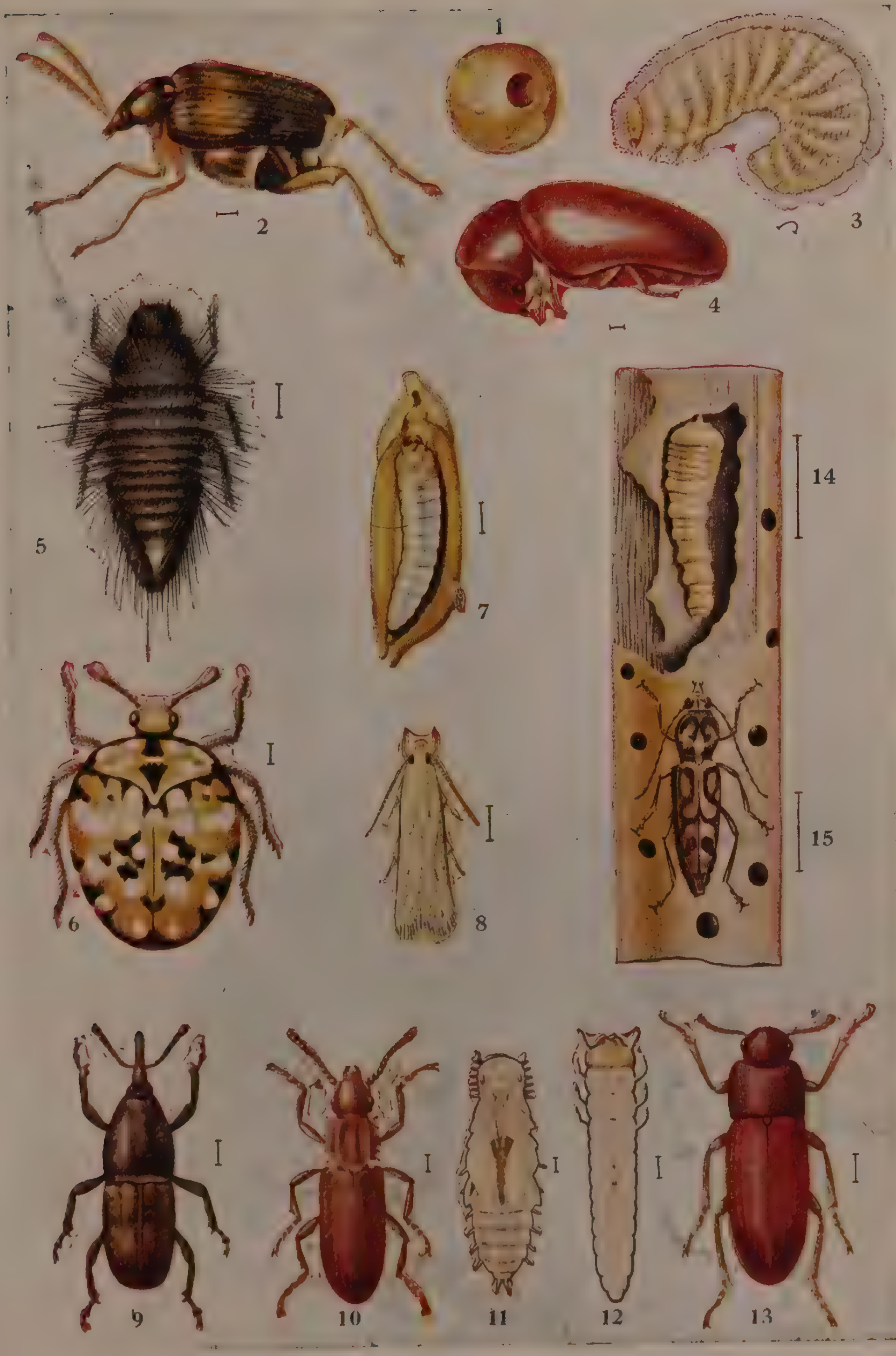
Fig. 1 shows an affected pea with two eggs on it and the hole of the exit of the Pea Bruchid (***Bruchus chinensis*** F 2), Fig. 3 is a grub of the cheroot beetle (*Lasioderma testaceum* Fig. 4) and Fig. 5 is the woolly-bear larva of ***Anthre vorax*** Fig. 6) which attacks skins, horns, woollen clothes and bristles used in making brushes. Fig. 7 shows the la of the paddy grain moth (*Sitotroga cerealella*) which is depicted below, Fig. 8, Fig. 9 is the Rice weevil (*Sitoph oryza*) and Fig. 10, the saw-tooth beetle (*Oryzaephilus surinamensis*) whose larva (Fig. 12) lives in dried fru dried 'mohwa' and similar vegetable matters : Fig. 11 is the pupa of this beetle, Fig. 13 is rust-red flour be (*Tribolium* sp.) which feeds upon grain and biscuits and has a great liking for dried insects. Fig. 14 show piece of an affected bamboo with the grub of the bamboo boring beetle (*Caloclytus annularis*) which is also depic there. For detailed information and remedial measures against the above pests refer to the *Indian Insect Pe* pp. 251-260

5. pupa, 6. adult (×7). Smaller outline ...

... hatch in 6 to 9 days, but ...

... with short, scale like appressed hairs ...

Oryzaephilus surinam...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oryzæ. It is sometimes a bad pest of somewhat moist grains, especially oats. The presence of the beetle in the food products, particularly cereals, makes them unpalatable and more often unsaleable. The flattish form of the beetle allows it to penetrate even tightly wrapped packages.

Life-history and habits

The adult is active in habits, slender, almost flat and brown in colour. It has well developed wings but seldom flies. The ovipositing females live 6 to 10 months. The total number of eggs laid by a single female has been found to vary from 45 to 285. They are dropped loosely among the foodstuffs or tucked in a crevice or inside a grain.

The egg is small, slender and white ; it hatches in three to five days in summer, but in cooler weather it may not hatch for about a fortnight even.

The larval period lasts from 12 days to as many as seven or even ten weeks, depending on the temperature conditions. The full-grown larva makes cells by sticking particles of foodstuffs together with a substance which it secretes. Often, the larvae crawl into a crack and surround themselves with particles of food glued together to complete these cells. Prepupal and pupal periods are passed inside such cells and are 1 to 4 weeks in duration.

Under most favourable conditions the development of the eggs up to the stage of the emergence of the beetle may be completed in 22 days. The longest period reported is 108 days at an average temperature of 69°F. The life-cycle from egg to egg may range from 27 to 315 days.

Tenebroides mauritanicus Linn. (Fig. B)

This species was described in 1758 and is popularly known as Cadelle or Yellow meal worm or the Bolting cloth beetle because of its common habit of cutting bolting-silk-net cloth and redressing machines in flour mills.

This species is widespread, being found in almost all parts of the world and is frequently found in mills, granaries and store-houses. There has been considerable difference of opinion as to whether this beetle should be considered as a 'grain', 'flour' or 'meal' beetle. In cases of heavy infestation 'maida' becomes stony hard and larvae lodge and feed themselves in specially constructed tunnels inside the mass. It can attack sound wheat and oat grains, though it usually confines itself to the soft embryo region. But if cut or already damaged grain is available, it is consumed entirely. The adult is an elongate, flattened, shiny-black beetle, about 1/12 in. long with the head distinctly separated from the rest of the body. It is reported to prey upon Rice weevils and thus prove beneficial, but it feeds upon grains even when Rice weevils are present. The beneficial effect, therefore, is negligible.

Life-history and habits

In summer the females begin to oviposit about two weeks after emergence ; during spring and autumn the preoviposition period is considerably longer, and in the case of adults emerging late in autumn no oviposition takes place until the following spring. A female may continue laying eggs for a period of 2 to 14 months.

Eggs are laid in batches of 10 to 40 in food material or in crevices of floors. Usually a single female lays about 500 eggs, but sometimes as many as 1,190 eggs have been noted. The egg is elongated, cigar-shaped, white in colour, measuring about 1·5 mm. to 2 mm. × 0·25 mm. It hatches in about six days.

The larva is one of the largest of the grain infesting insects and is easily recognized. It is about ¾ in. long, fleshy, with the abdomen terminating in two dark horny projections. It is pale-white in colour, with head, thoracic shield and the two horny projections at the end of the body being black. The larva developes very slowly and becomes full grown in 10 to 20 months. Unfavourable weather and food conditions may lengthen the larval life to three or four years. In damp situations larvae flourish well.

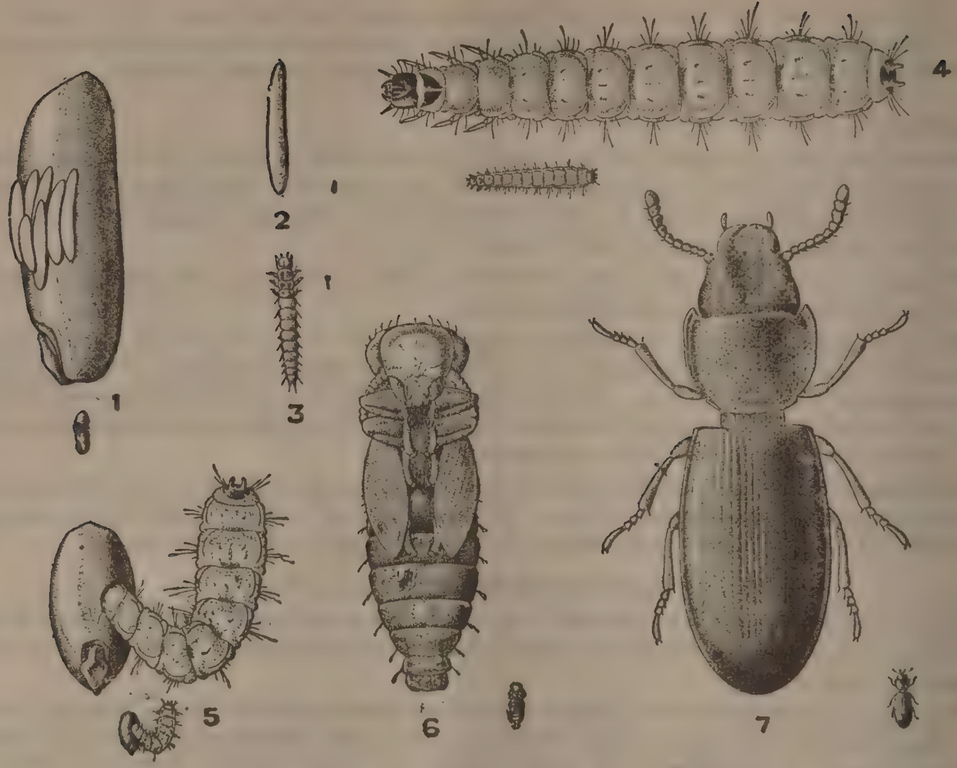


FIG. B. *Tenebroides mauritanicus*: 1. group of eggs on grain; 2. a single egg; 3. newly-hatched larv 4. full-grown larva; 5. larva gnawing into grain; 6. pupa; 7. beetle. Smaller outline figures show the natural size.

Pupation takes place either inside the corroded grain or between some grains fastened togethe The pupal stage lasts for 8 to 12 days.

Both the larvae and adults can live for considerable periods without food, remaining hidden the woodwork of the bins for a long time after the grain has been removed. When new grain is p into such a bin, it becomes infested in a surprisingly short time.

Laemophloeus minutus Oliv. (Plate IV, figs. 11—15)

This is commonly known as the Flat grain beetle. It is one of the smallest beetles found in stor grains. It is cosmopolitan in distribution and is one of the commonest pests of stored grain.

Life-history and habits

It is a small, flattened, oblong, reddish-brown beetle, about $\frac{1}{6}$ in. long with elongate, fillifo antennae, about two-third as long as the body.

The adult is apparently unable to attack sound, uninjured grain. It follows up the attack of t more vigorous grain pests and is found in association with the Rice weevil or Flour beetle. The larv are particularly fond of the embryo in wheat.

L. minutus is also a scavenger by nature and often infests grain and meal that is out of conditi The larvae also feed on dead insects.

The life-history of this beetle has not been worked out in detail. The small, slender, cylindrical white eggs are placed in crevices in the grain or dropped loosely in those floor, etc. The freshly emerged larva is cigar-shaped, about 0·7 mm. long, yellowish white, the head and the spine-like appendages on the anal segments being reddish-brown. The full-grown larva is creamy-white, with the terminal segment reddish-brown. The larvae make cocoons of a gelatinous substance to which the food particles adhere.

Under favourable conditions this insect may complete its development from egg to adult stage is about 6 weeks though generally it takes 9 weeks in summer.

Tenebrio molitor Linn. (Fig. C)

The pest is popularly known as Yellow meal worm or European meal worm. It is cosmopolitan in distribution. The pest is known primarily to feed on flour and meal, but also infests refuse grain, coarse cereal products and other mill products that accumulate under bags, bins, etc. because the adults show preference for damp and moulding materials which can be easily found in accumulations at such places. They have also been found in salt, soda ash, in ground black pepper, etc. The insect generally lives in dark and dingy places in the godowns, neglected corners in mills and under bags containing sweepings. Their presence would always indicate bad hygiene of the godown. Meal worms are used as food by small birds, amphibians and hosts of other animals.

The adult is black, about $\frac{1}{2}$ in. long and has well-developed wings. Males and females superficially look alike but they can be readily differentiated by the structure of the genetalia. The adults are liable to be easily confused with *Tenebroides mauritanicus* except for the sides in the thoracic region which are continuous in the case of *Tenebrio molitor*. The adults are relatively short-lived.

Fig. C. *Tenebrio molitor* Linn. adult

Life-history and habits

A single female on an average deposits about 275 eggs, which are laid loosely or in small clusters, and continues laying eggs up to a period of three weeks or so. Sometimes more than two months may be the frequency of oviposition. When first laid, the eggs are covered over with a sticky secretion that causes them to become quickly coated with the particles of food in which they are deposited. The egg is oval, opaque, milky white and shining 1·4 mm. to 1·5 mm. in length and ·60 mm. to ·66 mm. in width. Egg stage lasts from 7 to 10 days chiefly depending on temperature.

The newly hatched larva is white but becomes yellowish-brown with age, and is 2 mm. to 2·5 mm. in length. When full-grown, the larva is about an inch in length. Immediately after each moult the larvae are white but soon attain their normal colouring. When ready to pupate the larva

comes out on the surface of the infested food-material and passes a few days as prepupa. The larva may also wander about in the godown in swarms and be a source of creating unhygienic conditions Under favourable conditions the larval stage is completed in 6 months, but may last for a year o even more under adverse conditions of temperature and food.

The pupa is about $\frac{3}{5}$ in. long and $\frac{1}{5}$ in. broad. It is white when first formed but soon changes t yellowish-brown. Pupal period ranges from 6 days in summer to 18 days in winter.

Under favourable conditions the shortest period from the egg to the adult stage is about 200 days but as long a period as 629 days is also on record [Cotton 1929]. A mite *Caloglyphus mycophagu* is known to attack larval, pupal and adult stages.

Alphitobius piceous Oliv. (Fig. D)

This is popularly known as Black fungus beetle. It is found in damp and dingy parts of store below mattings, feeding on the waste grain-meal that lies accumulated there or in any similar accu mulations found in corners of stores, mills, etc. or on coarse grain and their products that are out c condition. It does not feed on sound grain. The pest attacks the moist and badly preserved grair In badly kept stores one comes across large number of these beetles and their larvae and on cannot escape noticing them immediately on entering the stores especially in areas of hig humidity, e.g. Bombay, Bengal, Assam, Cochin, Travancore, etc. It is, therefore, easy to concluc that the store hygiene is not satisfactory if this beetle is found in large numbers.

The adult is black or very dark-reddish in colour and is $\frac{3}{16}$ in. to $\frac{4}{16}$ in. in length. Th surface of the thorax is profusely punctured.

Very little is known about the detailed life-history of this insect but it is generally similar to tha of other meal-worms. Larvae are generally yellowish-brown in colour.

Fig. D. *Alphitobius piceous* Oliv. : 1. adult ; 2. larva full-grown ; 3. pupa

Gibbium psylloides Fab. *P.* (Fig. E)

G. psylloides popularly known as Hump beetle is a world wide pest of stored food. In India the pest breeding among the stored wheat was first recorded by Harchand Singh [1921] at Patiala. It as been reported to bore into the outer parts of opium cakes at Patna, and injure records in Dharwar. n other countries, e.g. the U. S. A., it is not an established pest and is not of any economic mportance, but judging from the variety of food it can feed on, and its quick breeding, it may become pest of economic importance in India. It is very common in Egypt and other parts of the East. Iost of the damage is done by adults. It feeds on cakes, yeast, wheat, dry bread, cotton seeds, aprika, cayenne, pepper, hay paste and gnaws even rubber mats. In fact it feeds on all kinds of lried animal and vegetable matters.

The adult has an egg-shaped body with stump part in rear. It is $\frac{1}{12}$ in. to $\frac{1}{8}$ in. long. The ulging back, glassy brown-red elytra, the fine, close, golden-yellow hair of its antennae and ong spider-like legs and down-bent head make the beetles easily recognizable.

The adult cannot fly, but walks rather slowly and cannot crawl up a smooth glossy surface ven if it is dirty.

FIG. E. *Gibbium psylloides* 1. larva (×16); 2. adult ; the smaller figure shows the natural size.

Life-history and habits

Very little is known about the details of the life-history. Eggs are laid among the foods usual on the surface. The egg is small in size and white in colour. It hatches in about a week's time

The grub is white with dark-brown mouth parts, body clothed with small, thin, light-brown silk hairs to which the particles of dust and food material get stuck giving the larva an appearance dusty colour. Head and antennae are very short, legs are also short and thin. The larv makes a hard whitish cocoon of anal secretion.

They have a very long life sometimes over three years. As the adults can live without foo for 35 to 50 days.

Sitotroga cerealella Oliv. (Plate V, figs. 7, 8 and fig. F)

It is commonly known as the Angoumois grain moth because as early as 1736 it was noted as pest in the Angoumois province of France. In America it is commonly called Fly weevil. In Beng it is known as 'survi'.

This species is found in all parts of the world and is one of the most destructive pests of unmille grain, being second only to the Rice weevil, *Sitophilus oryza*, in economic importance. When the grai lies exposed or is kept in receptacles which are not full, it literally swarms with this insect and damag is very considerable. The greatest damage occurs in the upper layers of grain in bags, bins, etc.

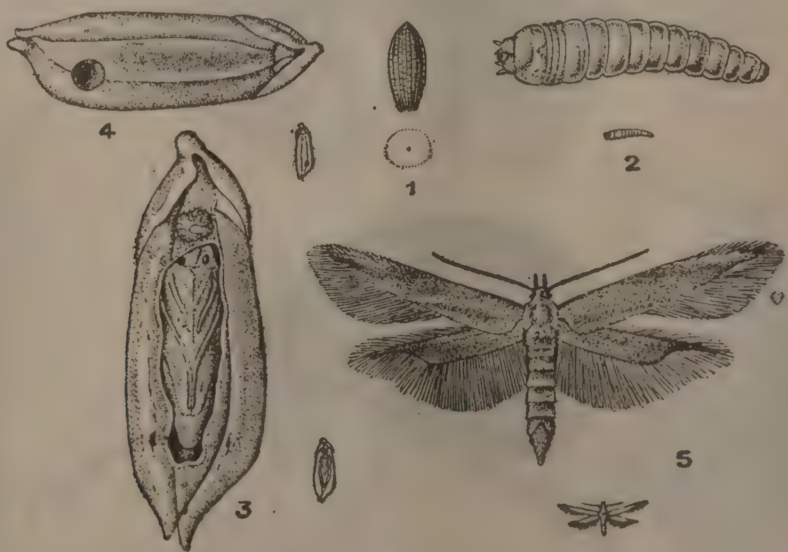


FIG. F. *Sitotroga cerealella*; 1. egg; 2. larva; 3. pupa inside attacked grain (cut open); 4. attacked grai after emergence of moth; 5. moth. Smaller outline figures show the natural size.

The initial infestation takes place when the young grain is in or passing through the 'milk stage in the field and usually a small percentage of grain kernels are infested. When wheat is in the straw it is easy for the moths to make their way from one wheat head to another as a result of which th infestation remains unchecked. By the time the grain is thrashed and stored, infestation by th moth increases rapidly. After the grain is thrashed and stored, it is impossible for the moths t make their way below the surface of the grain and infestation is restricted to the surfac

again. It is, therefore, highly desirable not to delay harvest. The moth also breeds in granaries. Injury to grain by this pest is always done in the larval stage. In the early state of infestation the injury is more difficult to detect, because the larva bores its way into the grain when it is so small that the hole by which it enters cannot be seen without the help of a magnifying glass. It is often noticed that after it has eaten its way into the grain, the larva turns about and spins a silken web over the opening by which it entered, thus making it even difficult to locate the entrance hole. Once it is in the grain, the larva eats out the kernel unseen and even unsuspected by the owner or those handling the grain. The first indication is provided by the almost simultaneous appearance of moths in the stores and the round holes that appear in the grain or sometimes by the 'heating' of the grain in the bin. The infested grains are hollowed out by the larvae and replaced by their excrement and webbing. The circular opening is not cut until the larva has become full grown. The moth is strong enough to push off this 'cap' when it leaves the grain. This is the emergence hole.

It is difficult to estimate the extent of loss caused by this moth to different stored grain but it may exceed 10 per cent or so. The actual weight of 1,000 kernels of sound wheat and like number of infested kernels showed nearly 50 per cent loss by weight as a result of the development of a single moth inside each kernel. Of course, the loss in weight varies with the ratio between the size of the kernel and the amount eaten by the individual insect in reaching maturity.

In the store the pest breeds as long as the food supply lasts. This period may be of several years' duration. If the pest is breeding in farm godowns, the moth is attracted by instinct to the nearby field in search of maturing grains in which to lay eggs for the first summer generation in the field. Of course, many moths remain behind in the granary and multiply continuously throughout the year.

General weather conditions, time of harvest, moisture content of grain, etc. are considered to be important factors which determine the abundance of the pest but the principal factor influencing its population is the temperature.

The moth is small, of about ½ in. wing expanse, buff or yellowish-brown in colour, with satiny lustre. It is distinguished from other common moths infesting stored products by the narrow, pointed wings, bearing wide fringes.

Life-history and habits

The female moth is capable of laying 120 to 400 eggs. These are deposited in depressions, cracks, crevices, in floors or holes in the grains. In Australia, this moth is known to lay eggs usually in the base of yet immature grain on the ears while they are still in the field [Wenhalz, 1927]. The eggs are white in colour when fresh, but soon become bright-red. They are oval in shape, about 0·5 mm. long, with both ends rounded. The surface is finely sculptured in the form of a fine network. The egg hatches in about a week's time. The tiny caterpillar crawls about and penetrates the grain, effecting entrance generally through a crack or abrasion in the pericarp. It feeds on the kernel and remains there for the rest of its life.

The full-grown caterpillar is about 5·0 mm. long. It eats out a small channel to the outside of the seed, leaving, however, a thin layer of the coat intact. A silken cocoon is spun, inside which reddish-brown pupa is formed. The larval stage lasts from two to three weeks.

After about a week's pupal period moths emerge through the thin seed-coat left by the full-grown larva at the end of the channel. The pest has usually three to four broods in a year. But sometimes eight broods have been noticed.

Parasites *Pteromalus gelechiae* Webster and a predaceous mite, *Pediculoides ventricosus* are the enemies of this pest, but they do not become numerous enough until the moth has caused much damage. They are, therefore, of not much practical importance.

Corcyra cephalonica Staint. (Fig. G)

This is popularly known as the Rice moth. This pest has a very wide distribution and occurs in almos every part of the world, including India, Burma and Ceylon. Due to lack of proper study this species was at one time considered to be of little importance in India, but now it is recognized as a serious pest of stored paddy, rice and other cereals in several parts of this country. Besides cereals and legumes, this pest has been noted on gingelly, oil-cakes, dried fruits, cocoa, chocolates, biscuits, flax seeds, 'suji' and 'atta', etc.

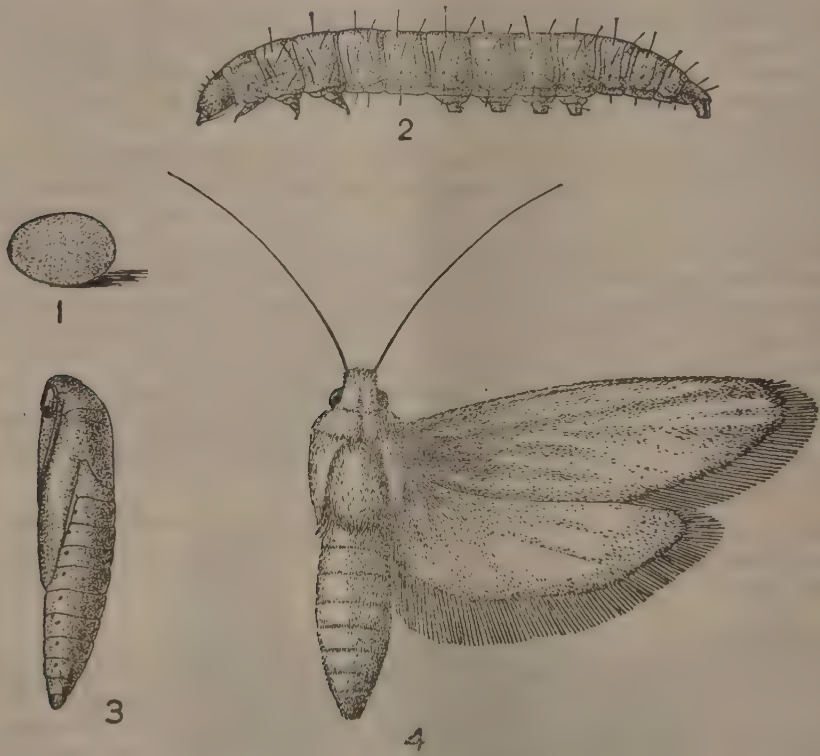


FIG. G. *Corcyra cephalonica* : 1. egg (×15) ; 2. larva (×9) ; 3. pupa (×6) ; 4. adult (×6)

Life-history and habits

The female moth begins laying eggs within a day or two after copulation. The eggs are laid indiscriminately anywhere on bags, walls, etc. a single female laying 90 to 200 eggs. The egg is small in size, white, more or less oval or elliptical in shape. It measures 0·5 mm. × 0·33 mm. The incubation period is about five days.

The young larva is creamy-white in colour, with a prominent, broad, yellowish head. The prothoracic shield is very distinct and light-yellowish in colour. The young larvae wander about for food and readily feed on the broken parts of the grain, but as they grow old they become capable of feeding on entire grains also. The larvae bore into the grains and pass their life feeding on the starchy matter. They web silken shelter which cover grain, frass, etc. so densely that it is difficult to detect their presence inside. The full-grown larvae live inside very tough and strong silken cocoons which are so densely woven with the grains that a thick felted mass of grain is formed into a large lump, or sometimes into a thick and flat sheet on the surface layer of the stored grain.

The larval period occupies 23 to 35 days, but sometimes it extends to over 50 days. The pupal period lasts on an average for 10 days.

Ephestia cautella Walker

This pest is popularly known as Almond moth, Dried currant moth, Fig moth. Its Tamil names are 'arisi puzhu' and 'baluhula' in South India where it is fairly common. It is found in most parts of the world and is a serious pest of dried fruits such as currant, raisins, dried apples, dates, berries, figs, almonds, walnuts, pistachu, etc. It has also been recorded some time ago on chocolates, cocoa beans, biscuits, tamarind seeds, on lac (in Bengal), malted milk, dried mango juice, garlic bulbs, and apricot seeds. *E. cautella* was considered to be of little importance as a pest of grain products. But of late we have found *E. cautella* seriously infesting important cereals and cereal products such as wheat, grain, flour, rice, etc. in different parts of India.

The larvae of *E. cautella* have also been recorded feeding on the aphid *Ceretoveuna lanigera* Zhnt. by Zehntner [1900]. Though *E. cautella* is primarily and mostly a pest of the store, in warmer countries it is known to maintain itself out of doors on figs in Asia minor [Smyth, 1911] and on date palms in Egypt [Gough, 1914].

Ephestia cautella adult is of greyish colour with transverse stripes on its outer wings. While at rest the fore part is elevated giving a distinct slope to the wings which are wrapped about the body. Wing expanse is less than an inch.

Life-history and habits

The female indiscriminately lays small, whitish eggs in the store in cracks and crevices and on the food itself. On an average about 250 eggs are laid by a single female. The eggs are laid principally during the first four days of laying and hatch in about three days or so at a temperature between 80°F. and 90°F.

The young larvae spill silk profusely and spin small silken tubes among the food particles or grain in which they remain lodged and grow. The full-grown larva is from ½ in. to ¼ in. long, white in colour with a pinkish tinge. Its characteristic colour and its habit of spinning tubes in the food material are the most conspicuous diagnostic characters. When infesting flour in mills, its silken tubes are in such large numbers that they sometime clog the mill machinery, necessitating its thorough overhauling. Larval period lasts from 40 to 50 days depending upon the prevailing temperature. The full-grown larvae spin cocoons and pupate therein. The pupal period lasts for about 12 days or so. The complete life-cycle takes about two months and thus five or six generations are possible in a year, if temperature conditions are suitable.

Nemeritis canescens Gr., *Microbracon hebetor* Say., *M. brevicornis* Wesm., *Trichogramma minutum* Riley are some of the parasites which parasitize the larvae. Predaceous mites such as *Pediculoides ventricosus* Newport are also known to attack larvae of *E. cautella*.

Plodia interpunctella Hubn. (Fig. H)

This pest is cosmopolitan in distribution. It is popularly known as Indian meal-moth, Meal worm moth, Compressed vegetable moth, etc. It feeds on a variety of food articles and grains. In fact, its food habits and adaptability to varying conditions have given it an almost universal distribution. It is said to be the native of the old-world and was first described in 1827. Very often the pest is brought into the pantry along with the food products from the grocery stores and it gets established in the house. Because of its feeding habits it is commonly seen everywhere in the house and is often mistaken for Clothes moth. It prefers the coarser grades of flour and milled products to fine grades. Whenever it has been found to feed on whole grain such as wheat, the larva was confined to the germ portion where an abrasion enables the larva to hold on to that part and feed further on the grain. The infestation by this moth sometimes assumes serious proportions.

The moth has a wing expanse of $\frac{1}{2}$ in. to $\frac{3}{4}$ in., and light greyish markings on the inner third of the forewings.

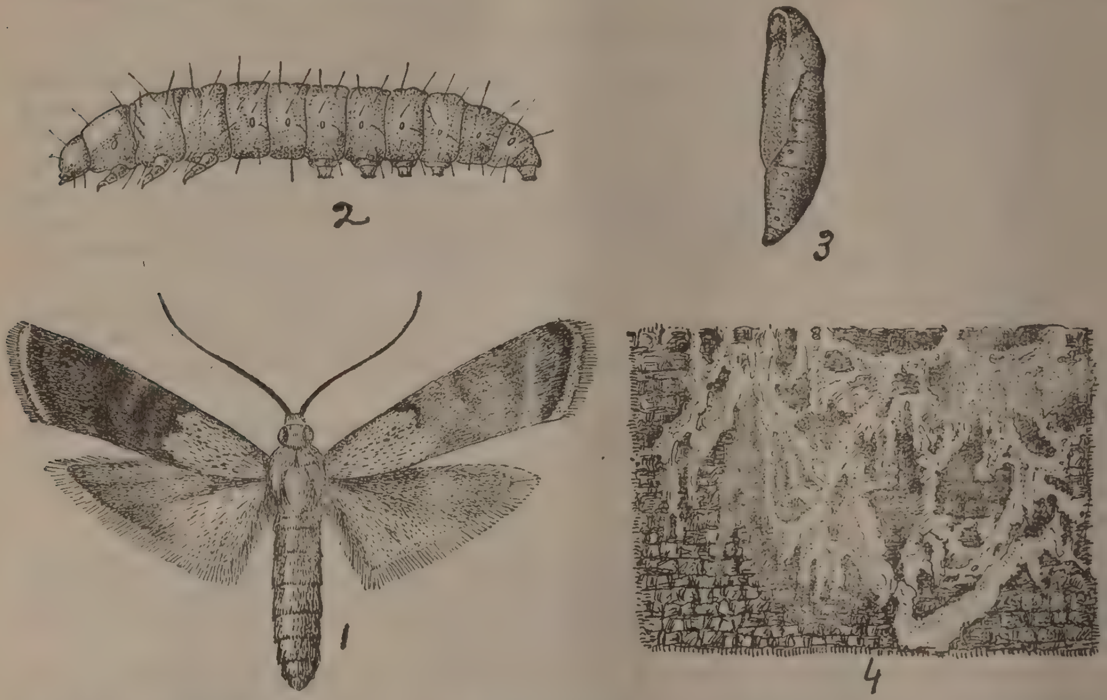


FIG. H. *Plodia interpunctella* Hubn. ; 1. adult ; 2. larva (full-grown) ; 3. pupa ; 4. part of the bag showing webbing

Life-history and habits

A female lays from 30 to as many as 350 eggs either singly or in groups on the food material. Generally the insect instinctively chooses the rough part of the material. The eggs are usually laid at night. The egg is small, ovate in outline, greyish-white in colour with the surface having granular texture. Eggs hatch in about 2 to 17 days depending upon weather conditions. Similarly the adults live for about 2 to 25 days.

The newly hatched larva is about 2 mm. in length and being transparent is very inconspicuous. Within a few hours after hatching they begin feeding and establish themselves in various ways upon and adapt themselves to different types and conditions of the food material. For instance in the case of raisins and apricots they lodge themselves in the external creases where they feed on the skin only. In other cases they form tunnel-like cases reinforced by frass and web together with silk the food particles upon which they superficially feed. An individual may construct more than one such tunnel. In cases of serious infestations, the larvae may spin silken sheets to completely cover the food material even in bags or bulk. The insect is only a superficial feeder. The larva becomes full-grown in about 30 to 35 days. The full-grown larva is $\frac{1}{2}$ in. long and varies in colour from whitish to various tints of yellow or green or pink. The colour depends on the nature of food taken in. The body is covered with fine hairs and the skin is granular. The larvae spin cocoons in suitable crevices in some inaccessible places. In some rare cases larvae may not spin cocoons and pupate naked. Pupa is light brown in colour and glossy in appearance. The pupal stage lasts for about 4 to 33 days depending upon temperature.

Under favourable conditions of temperature and humidity the life-cycle from egg to adult may be completed in a little more than a month, but under adverse conditions the insect may take 300 days to complete one life-cycle. As in the case of *Ephestia*, there may be five or six generations a year.

Among the natural enemies, parasites *Nemerities canescens* Gr., *Limneria ephestiae* Ashmed, *Microbracon hebetor* Say., *Dibrachys carys* Walk. are common.

Pyralis farinalis Linn. (Fig. I)

The pest is popularly known as the Meal snout moth. It is cosmopolitan in distribution. It prefers dirty and damp places to clean and dry ones and coarser and soiled articles to fine and soft materials. It is known to feed on oat meal, potatoes, seeds of mustard, coriander, sago, 'zira' (cumin), haricot weedings and other vegetable matters. It is reported to infest hay straw and other roughage as well as bran, meal and flour [Payne, 1925].

The adult has a wing expanse of about $\frac{3}{4}$ in. and is known to be the most beautiful of all insects infesting stored food products. The ground colour of the moth is light brown. The fore-wings are dark chocolate-brown at the ends while the middle is dusky white with two wavy white lines separating the lighter and darker areas on each wing. This colouring and moth's habit of bending its abdominal tip over the back when disturbed, make the moth more easily distinguishable.

There are two other species, viz. *P. pictalis* Curt. and *P. manihotalis* Guen. known from India as feeders on a variety of food articles.

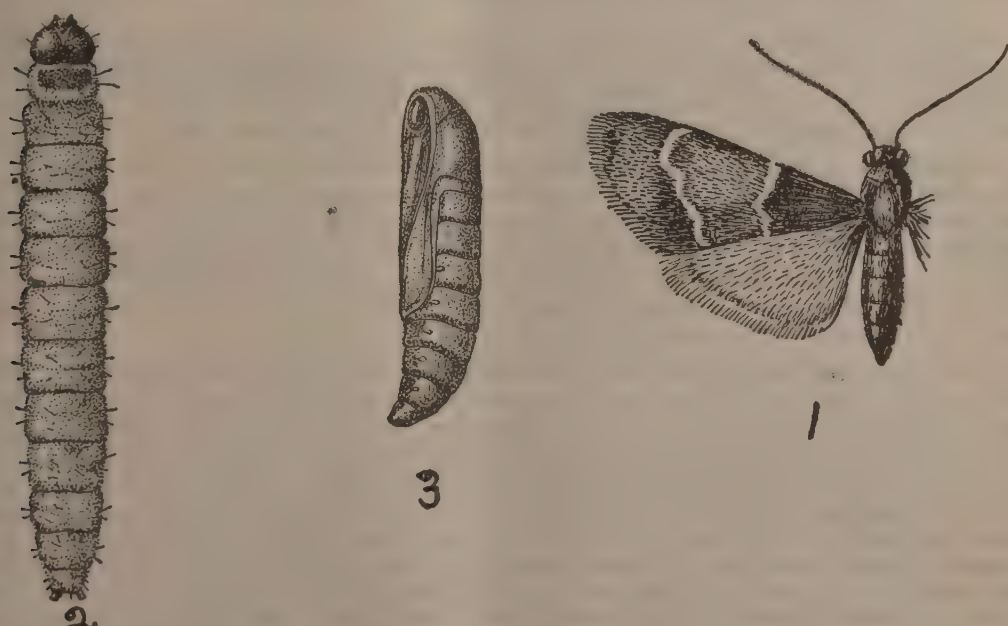


Fig. I. *Pyralis farinalis* Linn.; 1. adult; 2. larva; 3. pupa

Life-history and habits

In essential features and in broad outline the life-history of *P. farinalis* resembles that of *Ephestia* and *Plodia* species described above.

The larvae generally live in silken tubes which they spin in the material that they infest. The larva can be easily made out distinctly from those of the preceding two species. It is about ½ in. in length when full-grown, of smoky grey in general colour, darker at the ends with head brownish red. Mid-dorsal blood-vessel appears as a distinct dark line. Larva pupates in crude silken cocoon made up of the webbing and excrement, but occasionally it may not form cocoon and pupate naked. Pupa is 5 mm. to 7 mm. long, dark brown in colour when fully scrutinized. The pupal stage lasts from 5 to 30 days.

(ii) Pests and pulses

All the important pests of stored pulses belong to the family Bruchidae of the order Coleoptera. According to their habits, these beetles can be grouped as follows :

(*a*) Those which remain only in the store, breeding in stored grain.

(*b*) Those which breed both in the field and in the store. The largest number of pulse pests belong to this category. They infest grain while still green in the field. With harvested grain they find their way into the store where they continue feeding in the dry grain. The damage is considerably more in the store than in the field. They are capable of invading fresh stores and attacking whole grains which are harvested in sound condition.

(*c*) Those which infest the grains in the fields and are brought into the store with the harvested grain but do not breed in the store.

The Bruchidae are small insects, rarely exceeding ¼ in. in length, are sombre and inconspicuous in colour and have their bodies clothed with short hairs. The head is small, with a blunt rostrum and short antennae which are often pectinate or serrate. The prothorax is well developed. The elytra are truncate, not covering the last segment. The legs are short, the hind femora thickened.

Adult Bruchids fly from the infested stores to the nearby fields where pulses are growing. As the pods develop, the female lays eggs either on the outside or within the pods. The eggs hatch into white grubs which burrow their way through the pod wall into the soft-developing grain inside. Since the grubs are very tiny, the holes through which they enter the grain are too small to be seen with the naked eye. As the grains enlarge and harden with the ripening of the pod, the holes in the skin through which the grub entered become less and less easy to find. The wound on the skin either gets entirely healed or is too small to be noticed.

Since pulses mature faster than the grubs within them many grains that appear outwardly in sound condition, may really be very badly infested. When the grain is stored the grubs continue to feed inside and become full-grown. In due course they eat out of the grain contents a cavity somewhat larger than themselves, extending outward to, but not puncturing the outer coating of the infested grain. The grub then transforms into a pupa and eventually into an adult. The beetle has a sharp pair of jaws which it uses like a pair of scissors to cut out a circular flap in the grain coating thus making a small round hole which is the first evidence of the presence of the insect inside the grain. Through these openings the adults emerge and come up to the top of the grain heap. They may remain there without flying if they are kept undisturbed. Usually when the store is opened they appear to be disturbed and a number of them escape. The beetles start laying eggs on the grain, preferably those which had escaped the infection in the field and the cycle starts in the store. The breeding is heavy or slow depending upon various factors like temperature, humidity and the method of storing. After a number of generations have been passed through in the store, the beetles by instinct rush to the field and start the cycle afresh. Sometimes a small number of the individuals from each generation also move to the field and infect the crop there.

FIGS. 1, 2, 3. *Pachymerus (Bruchus) chinensis* Linn.
FIGS. 4, 5, 6. *Bruchus analis* Fabr.
FIGS. 7, 8. *Bruchus phaseoli* Gyll.
FIG. 9. *Bruchus albocallosus* Pic.

The small figures by the side of the larger ones indicate the natural size of the insects

The more important species which damage pulses in India are listed below :

1. *Pachymerus* (=*Bruchus*) *chinensis* Linn.
2. *Pachymerus* (=*Bruchus*) *quadrimaculatus* Fabr.
3. *Bruchus analis* Fabr.
4. *Bruchus albocallosus* Pic.
5. *Bruchus phaseoli* Gyll.
6. *Laria* (=*Bruchus*) *affinis* Frol.
7. *Laria* (=*Bruchus*) *emarginatus* All.
8. *Laria* (=*Bruchus*) *pisorum* Linn.

A brief general account of the most important species is given below:

Pachymerus chinensis Linn. (Plate VI, figs. 1—3 and fig. J)

It is found in all parts of India and is generally known as Cowpea weevil in America. It was first described from China in 1758. Although it is a pest of minor importance in America and other countries, it is certainly a very serious store pest in India, causing enormous damage to almost all kinds of pulses.

The adult is about $\frac{1}{8}$ in. long and can be distinguished from other species by the elevated ivory like spots near the middle of the body.

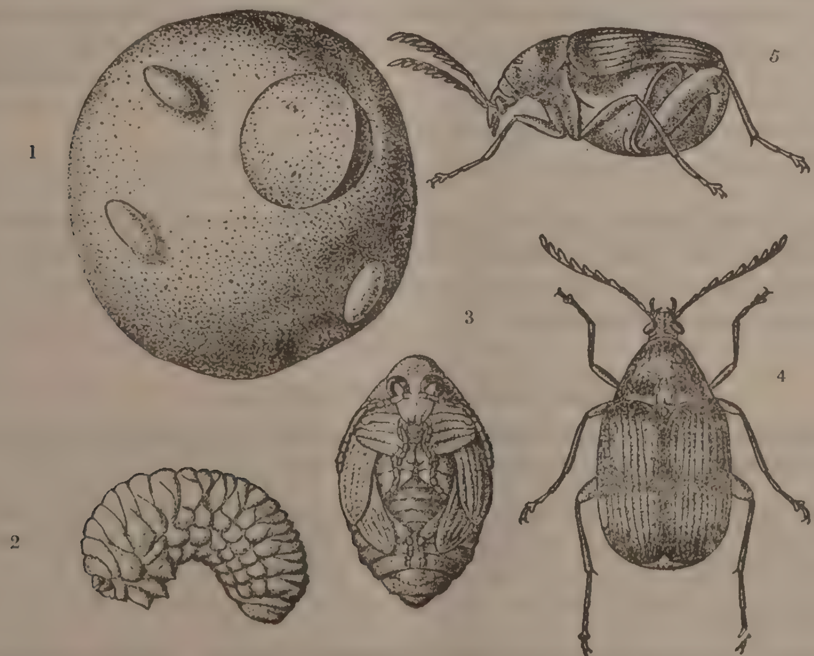


FIG. J. *Pachymerus chinensis* ; 1. Attacked seed with three eggs and hole of emergence of beetle 2. larva ; 3. pupa ; and 4. and 5. dorsal and lateral views of beetle (x 12)

As its popular name indicates, this beetle prefers cowpea but it has been reported to feed on several other hosts also, viz. *Pisum sativum* (pea), *Pisum arvense* (small peas), *Dolichos lablab*, *D. biflorus*, *Cicer arietinum* (gram), *Cajanus cajan* (arhar), *Lens esculenta* (lentil), *Vigna catjang* (cowpea), *Phaseolus radiatus* (mung), *P. mungo* (urid), *P. aconitifolius* (moth), *Glycine hispida* (soybean), *Lathyrus sativus* (khesari) and *Vicia faba*.

Life-history and habits

The eggs are laid singly, but several of them can be seen on one grain. In the field, the eggs are laid on green pods. They are glued on to the surface of the grain. The egg when freshly laid is translucent, smooth and shining but becomes pale yellowish or greyish white with age. It is elongate and oval in shape.

The egg hatches in four to five days and the young grub burrows into the pod or grain. In the case of a pod, a small hole is visible under a lense below the empty egg shell which is surrounded by plant tissue thrown out by the grub while it feeds and works its way in.

The larvae feed and develop inside the grain and are full-grown in 2 or 3 weeks during summer. A fully developed larva is about ¼ in. long, is cylindrical in shape, fleshy, strongly wrinkled, perfectly white except in the region of its mouth parts which are brown. It remains lying on the seed in a curved state.

The pupal stage lasts for about four days in summer but considerably longer in cool weather. The adult gnaws its way out of the grain by pushing open a slit-like round piece.

Besides temperature, the nature of the grain on which the beetle breeds has an important effect on the duration of the life-cycle [Ghosh, 1937]. On *Cajanus cajan* the life-cycle occupies a maximum of 43 days in January and February and a minimum of 25 days in March and April ; on soybean it is 41 days, on *Lens esculenta* 34 to 41 days, and so on. On grains which were not congenial to the beetle, and on which it would live and breed with difficulty as was evidenced by the small size of the offspring, the life-cycle was much lengthened.

Natural enemies

Bruchobius laticeps Ashmead is a larval parasite of *P. chinensis* and *Bruchus analis*. The percentage of parasitization is known to vary between 29 and 67 from September to January.

Chaetostricha mukerjii Mani is known to parasitize eggs of *P. chinensis* and *B. analis*. About 58·3 per cent of eggs may be parasitized.

Bruchus analis Fabr. (Plate VI, figs. 4—6)

This species is closely allied to *Pachymerus chinensis* but differs from the latter in the absence of the ivory-like spots in the middle of the dorsal side of the body.

It has been recorded from several parts of India and is generally found, especially in the Punjab, in association with *P. chinensis*. *B. analis* can breed in the store only, its activities in the field being very much limited.

Life-history and habits

Copulation and oviposition start soon after emergence of beetles. Eggs are deposited singly or in groups on the surface of the grain and pods. In its general biology, habits and larval appearance *B. analis* is similar to *P. chinensis*.

Bruchus phaseoli Gyll. (Plate VI, figs. 7-8)

B. phaseoli is fairly widely distributed in India as well as outside in other countries, e.g. Brazil, Jamaica, Hawaii, France, Italy, etc.

This species differs from the preceding two species in being slender, slightly longer and having longitudinal whitish or pale yellowish markings on the elytra. Probably the species recorded as *Bruchus* sp. on lablab in Madras [Rao, 1917], on beans in store at Pusa [Fletcher and Ghosh, 1921] and as *Bruchus theobromae* in South India [Fletcher, 1914], were all *Bruchus phaseoli*.

This pest attacks pulses in the field as well as in the store. Therefore, unless properly looked after, grain is liable to serious damage in a very short time. It is known to be a very serious pest of *Dolichos lablab* in store. In captivity it has been bred from pigeon pea, cowpea, soybean, chick-pea (*Cicer arietinum*), *Phaseolus angularis*, broad beans, ' mung ' (*Phaseolus mungs*), *P. arvense* and common pea.

Life-history and habits

The adults mate soon after emergence. In the field, eggs are laid on green pods usually in clusters and several may be laid upon the same pod. The eggs are almost cylindrical or elongate, or oval in shape, with a shiny surface at first pearly-white in colour, changing to light yellow with age. The egg clusters are held together on to the surface of the pod by a gummy substance of the same colour as the eggs.

In the store the mode of oviposition is different from that in the field. Eggs are laid singly, although there may be many eggs on the same grain. In the store, dry grains have been observed to be preferred for oviposition to green pods supplied.

Other immature stages are similar to those of the preceding species described above.

The life-cycle takes about 18 to 38 days, varying with the temperature and the food supply as in the preceding two species.

Laria affinis Frol. (Fig. K)

L. affinis is commonly called Pea bruchid because of its special liking for small peas (*Pisum arvense*). It occurs in other parts of the world also.

This species like *Bruchus phaseoli* attacks the grain while they are still in green pods in the field and its damage is continued in the store but it cannot breed in dry grain. It is not so serious as other species described above, especially because of its low incidence as it breeds only once a year.

The adult is oval, black, with upper side dark brown and covered with white hairy spots. The first four antennal segments and forelegs are reddish-yellow.

Life-history and habits

Eggs are deposited singly on the surface of green pods in the field during January and February. A single pod may have as many as 17 eggs. The egg is elongate, oval and cylindrical in shape, measuring 0·06 mm. in length and 0·25 mm. across, and is orange-yellow in colour.

The young grubs gnaw their way into the pods and attack the grain inside, where they feed and grow and come into the store along with the harvested grain. Though they become adults by about May-June, they do not leave the sheds before July. Emergence on a large scale takes place in December and January when the beetles fly out and lay eggs, thus completing only one generation a year.

Laria pisorum Linn.

L. pisorum commonly known as the Pea weevil does not breed in the store as is the case with *Laria affinis*. This is the largest of eth pea of bean feeding weevil.

FIG. K. *Laria affinis* ; 1. Eggs laid on pod (x4) ; 2. egg (x16) ; 3. larva (x8) ; 4. seed after emergence of beetle (x4) ; 5. beetle (x8). Smaller outline figures show the natural size.

It is known to occur in all parts of America and Europe. Its original home is probably America. Except by Lefroy [1909] there is no record of its being a serious pest in India.

The adult measures about 1/5 in. in length and 1/10 in. in width. Its ground colour is black, but the body is thickly covered with brown pubescence variegated with black and white markings. The sides of the thorax are notched and the abdomen which projects beyond the elytra is covered with whitish pubescence and marked with two black spots.

Life-history and habits

When peas are in blossom, the eggs are deposited singly on the surface of the pods to which they are attached by a peculiar viscid secretion which turns white on drying. The egg is yellow, about 1/20 in. in length.

This newly hatched grub bores through the pods into the grain when it casts a skin, after which it settles down to feed on the kernel of the grain. When full-grown, it eats out a circular hole near the surface of the grain, leaving only thin outer membrane as a covering, after which it rests, and pupates inside the grain. In this stage the insect remains for about seven days or so.

L. pisorum has also only one generation in a year. As it does not breed in dry grain, the new generation for another year is dependent on such beetles as are contained in sown seeds or which escape from the storehouse.

Bruchus albocallosus Pic (Plate VI, fig. 9)

The favourite host of this species is *Cajanus cajan* and the attack starts in the field. The mode of oviposition and infestation of the young grain by this beetle is almost the same as in the case of *Laria Pisorum*. This species has not yet proved to be of much economic importance.

Pachymerus quadrimaculatus Fabr.

This species is commonly called Four-spotted bean weevil. It resembles *P. chinensis* in its life-economy. In appearance, however, it differs from it in many characters. It has black ground colour, with black, grey and white pubescence, serrate antennae, longer and grey elytra with white pubescence so arranged as to leave four large black spots from which the species derives its name.

It breeds more rapidly in fresh and slightly moist grain than in dry ones.

Two Chalcid parasites, *Bruchobius laticeps* Ashm. and *Aplastomorpha pratti* Asham. are known to be its natural enemies.

(iii) Miscellaneous insect pests

There are many other pests which do not breed in stored grains but their presence in our food stores on foraging expeditions is objectionable more on account of the filth and the nuisance that they cause in the store than because of the amount of food consumed or contaminated by them. These insects are cockroaches, ants, crickets, silver fish, psocids, white ants, etc. Each of these insects belongs to a different family, but they are common in so far as they are a general nuisance in a store. They cause enormous losses in a variety of ways. These insects have been in intimate association with man and they are too well-known but yet only little is known about them apart from what every householder knows about their sudden appearance and disappearance in different season.

Cockroaches (Plate VII, figs. 1—4)

The cockroach is a cosmopolitan pest found throughout the world. Cockroaches are quite common in houses in Northern India, but the damage they do is relatively small. In Bihar, Bengal and in those parts where the climate is comparatively hot and moist they do considerable damage and are, therefore, considered as among the worst domestic pests. During rainy season they can be seen in huge numbers in the provision stores breeding beneath any bags, matresses or stacks of bags. In places where large stocks have been kept undisturbed for over long periods they can be seen all over the place ; egg-cases sticking every where on bags, walls, etc. In cases of heavy infestations bags are often seen studded with egg cases as a result of which bags of grain are considerably weakened.

There are several species of cockroaches which are found in India. *Periplaneta americana* (Fig. 1) is the commonest of all and is found in all parts of the world. The other species in this country is *P. australianae* (Fig. 2) which is confined to Southern India and Ceylon. *Blatta orientalis* and *Blatta germanica* and *Stilopyga rhombifolia* are also found in some parts of India.

Cockroaches are flattened insects. They have horny, smooth and slippery bodies and large spiny legs for fast running. Their colour is generally brown or dark brown. The head is inflexed under the body and the antennae are long, slender, whip-like structures which are usually moved side ways. Their mouthparts are well developed and include strong biting jaws which enable these insects to eat all kinds of food. They are omnivorous insects feeding on almost any cereal products and all sorts of provisions in the store. Their favourite element in any food is the starchy part of it Wherever they can find it they will scrape or scoop that out, disfiguring and discolouring the article they feed upon.

They usually live in dark places. hidden in cracks and crevices, in groceries, stores, packing boxes, pantries, etc. They are seldom seen in the day time and come out only at night when they prowl about and do the actual damage. In the places which are dark and dingy they continue their ravages during the day also. It will be seen, therefore, that heat, moisture, darkness and plenty of starchy food are the ideal conditions for their breeding.

Another way in which they cause loss is that they taint the food unpleasantly which cannot be redeemed and goes into waste. Cockroaches give out, wherever they occur in some number, a foetid, nauseous odour well known by the name 'roachy odour' which cannot be removed easily from the food.

Life-history of almost all the species named above is generally similar in essential features. The eggs are laid in bean-shaped capsules ; the capsules are arranged in two rows (Fig. 3). They are cigar-shaped. The number of eggs in a capsule varies with different species. The eggs hatch in about two days during summer but in winter they take longer to hatch and this period may be several weeks. The freshly hatched young ones are often kept together by the mother who broods over them and cares for them. The young nymphs (Fig. 4) develop and grow and periodically cast their skins. The number of times they cast their skins is variable and depends mostly on the food available and several other local factors. After sometime their wings start appearing and go on developing till they become adults when the wings acquire their full size. The period between the hatching of the nymphs and its reaching the adult stage is invariably dependent upon climatic conditions and food supply. Generally there is one generation in a year.

The abundance of cockroaches is not so much due to the rapid rate of multiplication as to their ability to protect themselves from ordinary means of destruction. Their flattened bodies enable them to get entrance through very narrow cracks and crevices for shelter against any attack.

Crickets (Plate VIII, figs. 5 and 6)

Crickets are dull, straw-coloured insects having some irregular black spots on the head and thorax. They are generally little over an inch long. The wings are deflexed and usually lie flat over the body when at rest. In some species the females have no wings or the wings are just rudimentary outgrowths. The extremity of the abdomen is provided with two long, slender appendages and in the case of females there is in addition a long and fine ovipositor with the help o which eggs are laid. Of the three pairs of legs, the hind legs are much bigger and well suite for jumping. A little approach makes them take a long leap.

There are two species commonly found in the house, stores, etc., viz. *Gryllulus domesticus* an *Gryllus sigillatus*. They cause an enormous amount of damage to household articles includin cereals and cereal products. They are omnivorous insects, and their mode of damage is much th same as that of cockroaches. They also like starchy food and bread, biscuits, flours, etc. The damage silk fabrics particularly of rayon and woollen articles also.

Crickets are seldom seen during the day time, when they remain hidden in cracks and crevices behind hanging clothes, wall papers, hanging pictures or looking glasses, etc. In such situation one can see numbers of them in different stages. In stores and groceries large number o crickets can be seen beneath mattings, etc.

Crickets thrive best in damp and warm places. Parts of those stores or houses which are les frequently disturbed also become the favourite haunts of the crickets. They are found throughou the year but are especially active during the rainy season and autumn. Their presence in a stor indicates bad hygienic condition and dampness. Crickets are capable of living outside the buildin under dumps and refuse or in gardens. With the onset of winter they may again get into the stor or any building where it is comparatively warmer. *Gryllulus domesticus* seems to breed alway outside the house. In fact, damage in the store or the house to various foods and other articles caused by adults, the younger stages being common in the field. When they are found in larg numbers, they swarm the grain bags and cut their way inside the bags and scrape away the oute embryonic portion of the sound grain. 'Atta' gets very badly infested by crickets.

FIG. 1. *Periplaneta americana* L. (Adult stage) $\times 1\frac{1}{2}$

FIG. 3.
Egg-case with two longitudinal rows of eggs $\times 3$

2. *Periplaneta australianse* Fab. (adult stage) $\times 1\frac{1}{2}$

FIG. 4.
II instar nymph of *Periplaneta americana* L. $\times 6$

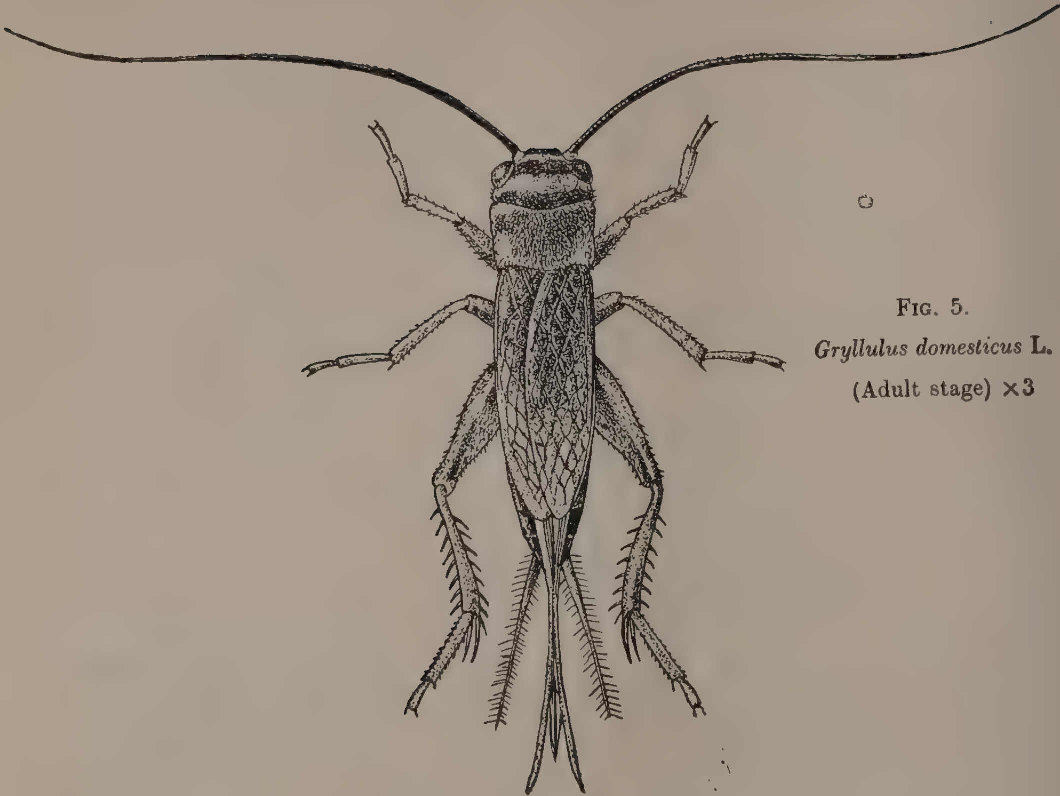


FIG. 5.
Gryllulus domesticus L.
(Adult stage) ×3

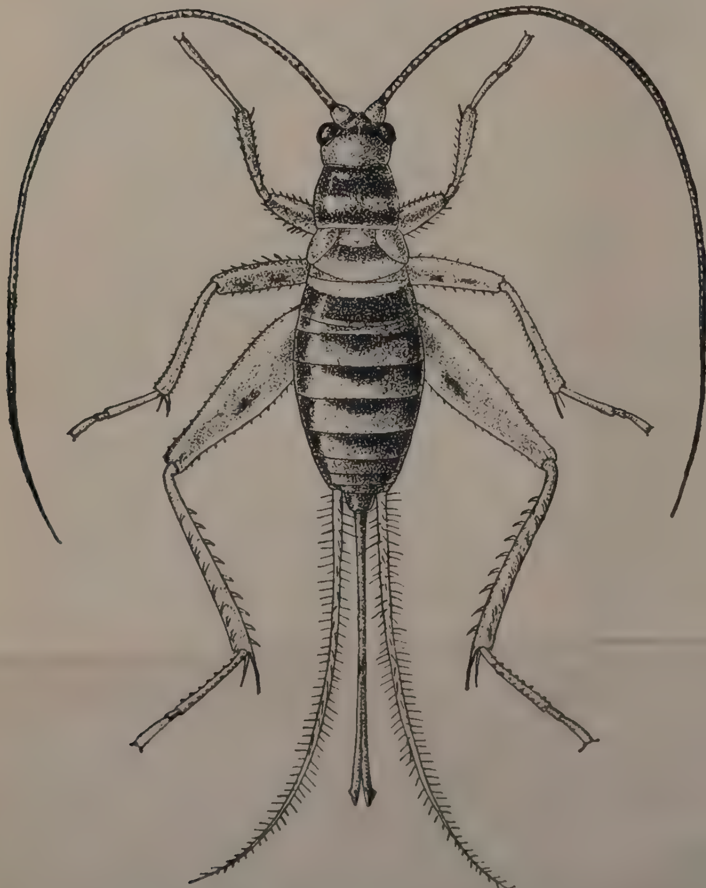


FIG. 6. *Gryllus sigillatus* Wlk. (Adult stage) ×6

FIG. 7. *Lepisma saccharina* Linn.

The female lays eggs in clusters of about 30 eggs each. The eggs are more or less cylindrical in shape and yellowish-white in colour. The young or the nymphs are similar to the adults in general shape except that they have partially developed wings. It takes about three months for the nymphs to reach maturity, but this period may be longer under cool and dry conditions. Both the adult and the young are capable of causing equal damage. There is usually one generation in a year.

Ants (Figs. L, M, N.)

There are few insects which have proved more persistently exasperating to any housekeeper or store-keeper than ants. In an infested store or house the worker ants are found crawling over any food that is to their liking, bits of which they cut off and carry to their nest. Some carry away whole grains. Some species cause injury by making nests in the masonry and wood work of old stores but, as a rule, they do not attack sound wood. This factor should be given consideration in making selection of stores.

The food of ants is even more varied than that of man. They attack fats, meals, roots of vegetables, sweets, grain, etc. They are fond of nearly every kind of human food and, besides this, in some places they gather and store quantities of grain in their nests.

Ants are small animals closely allied to bees, wasps, etc. Ants as a group can be distinguished from other insects by having one or two wart-like elevations on the slender pedicle-stalk that separates the thorax from the large part of the abdomen.

The ants, that are generally noticed moving about, are the worker ants which are sterile females and are only one of the numerous forms that occur in the ant colony. They cannot exist alone. They usually enter the house in large numbers in search of food and moisture. They always look as if in great hurry and some times they go to long distances between the source of food supply and the nest. They feed on sweet and greasy substances. They get into anything unless hermetically sealed. They are well-known for their industrious and social habits.

It is seldom realized how much grain can be taken away when a large number of worker ants invades any godown, each individual continuously working the whole day carrying one grain at a time to its nest. Millions of grains carried to the nest or taken out of the store and scattered about will be more than a maund. This is specially true of Carpenter ants. It is, therefore, important that ants should not be looked upon with indifference.

The winged males and females which swarm out of the nest at certain seasons are also very conspicuous. But the wingless females called 'queens' and helpless maggot-like youngs remain exclusively in the underground nests and are very seldom seen. In some colonies even the worker form is divided into two or three types.

A typical colony consists of one or several females or 'queens' whose function is to lay eggs and develop thousands of workers, which, as mentioned above, are incompletely developed females and seldom lay eggs. The queens are cared for by the workers and usually remain in the inner chambers of the nest, seldom leaving it except at times when the colony may migrate to a new location.

It is usually seen that when the nest is disturbed, the workers take away the queen to some safe place where they establish a new colony. The majority of larvae or maggots , develop into workers after going through the pupal stage either in a cocoon or without any such protection. A certain percentage, however, develops its winged males and females—the 'kings' and 'queens' of the future ant colonies. At certain times of the year, varying with the species, these winged males and females leave the nest in swarms. This usually occurs over a wide area on the same day for any one species. The males die soon after mating. The female flies to a situation that is attractive to her as a nesting site, alights on that site, tears off her wings, encloses herself in a small cave which she herself excavates in the soil and in which she lays eggs. After the eggs have hatched, the female feeds and cares

for the young larvae until they are full grown. The ant larvae are whitish, helpless like maggots, without legs and with very small heads. The larvae develop into workers and as soon as the adult workers appear, they start taking care of the 'queen' and her young. From this time on, the 'queen' confines her activities entirely to egg-laying. The queen may live from one or two to 12 or 15 years, during which time she will produce many thousands of eggs which may give rise to thousands of individuals.

There are several species of ants in India but only a few are known to be troublesome in the house or the store. They are, *Dorylus labiatus*, *Monomoriun indicum* and *Camponotus compressus*.

The workers of *Dorylus labiatus* Shuck (Fig. L) are bright red-brown, highly polished, shining and smooth insects, with minute dot-like pits on the body. This species is found throughout India. It builds its nests outside the house, the workers go foraging in the house.

Monomorium indicum (Fig. M) is a small, tiny insect with head and thorax red and legs brown, abdomen dark-brown or black and rounded. This species is practically omnivorous. It builds nests generally in any inaccessible place near the foundations and walls of buildings from which it forages indoors all the year round in search of food. It is rather very difficult to eradicate them. They attack woodwork and masonry also.

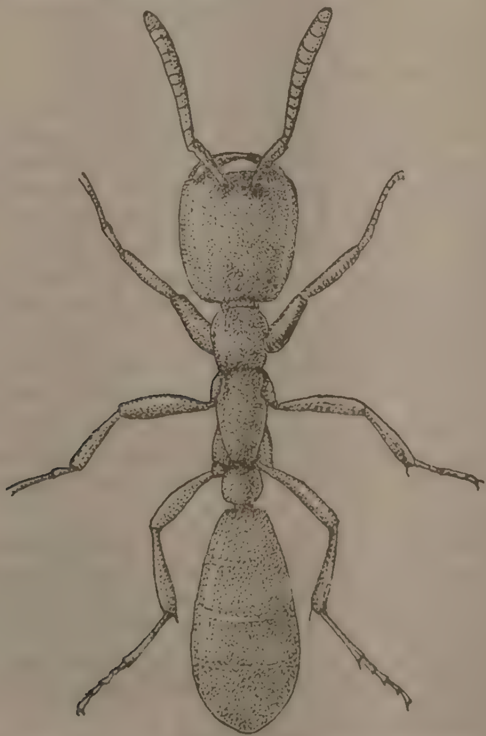


FIG. L. *Dorylus labiatus* Shuck (worker) (×12)

Camponotus compressus Fabr. (Fig. N) is commonly known as the Carpenter ant. It is a black, opaque insect with body having five dot-like pits and shining abdomen which is comparatively broad and massive. It is capable of doing immense damage to woodwork of old buildings.

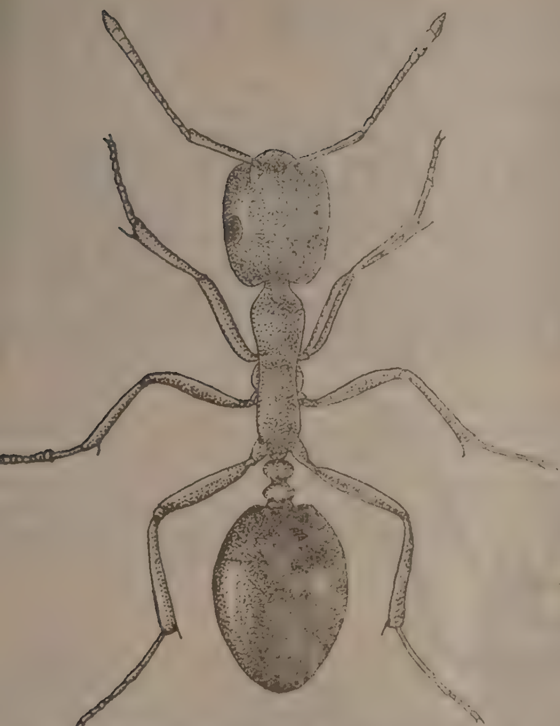


Fig. M. *Monomorium indicum* Forell (worker) (×18)

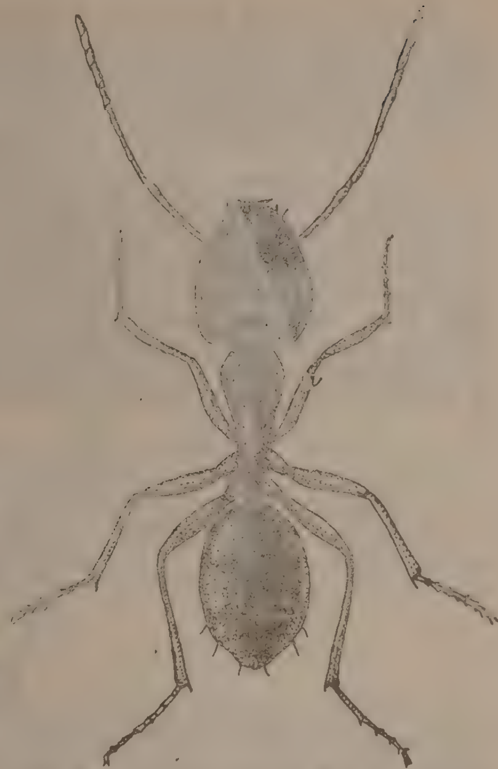


Fig. N. *Camponotus compressus* Fabr. (worker) (×4½)

Silver-fish (Plate VIII, fig. 7)

Like other store pests, these insects are well distributed in India. They are known by a variety of names, viz. Silver-fish, Silver-moth, Sugar louse, Sugar-fish, Fish moth, Sticker and Bristle tail. Silver-fish belong to the most primitive groups of insects, Thysanura, and the species commonly met is *Lepisma saccharina*. It is about ⅓ in. long, with the body tapering from the head to the tail end and is clothed with glistening silvery scales which give the body a uniformly grey colour. Like all other members of Thysanura, it does not acquire wings at any stage of its life. There are two long, slender, many jointed feelers projecting from the head and three long tail-like appendages extending backward from the hind end. The mouth parts are better suited for scraping than for chewing purposes. The protective colouration of the insect, the rapidity with which it moves and the fact that the body is soft make it almost impossible to capture a specimen without crushing it.

Silver-fish thrive in dark, moist places, shunning lighted, dry and well-ventilated places. They also collect behind wall papers, etc. In some of the dark and dingy stores, they may be found on bags and walls which would show that stores are damp and dirty. They feed on a large variety of materials both of vegetable, such as flour and oatmeal, etc. and animal origin. Their preference seems to depend largely upon the nature of food supply available to them early in life. If they are habituated to feed on starch, they will maintain a steadfast preference for such material and will starve rather than feed on any other material.

There are a number of ways by which Silver fish may get into dwellings. Usually they are dependent upon infested material or containers used for transportation.

The life-history of *Lepisma saccharina* Linn. is very simple. Each female usually lays 7 to 12 small, whitish eggs in crevices and other concealed places. They hatch in 6 to 12 days, the young closely resembling the adults except in size. The development is completed in about nine months during which period the individual casts 6 to 7 moults. In temperate climates it may take as long as two years to reach maturity.

Psocids

They are commonly called the Book lice and are soft bodied insects found nearly in all parts of the world. They are $\frac{1}{25}$ in. in length and are dirty, grey or pale yellow in colour. They have chewing mouth parts and are generally feeders on either animal or vegetable matters. They are often seen in flour and grain and may swarm over grain in large numbers. They do not cause much damage by their feeding but their presence is rather very annoying. They seem to prefer dark, damp, dingy and mouldy places. Apart from the direct migration into the house they may also gain entrance either through infested mattresses or upholstered straw mattings, etc.

There are two species of the Psocids which are commonly found in India, in fact, in most parts of the world. They are *Liposcellis transvallensis* (Fig. O) and *L. divinatoria.*

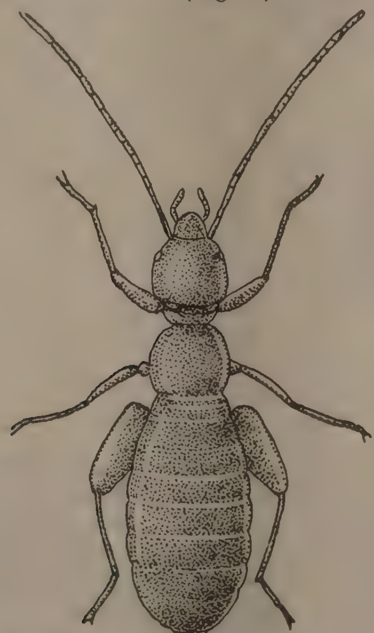


Fig. O. *Liposcellis transvallensis End.* (adult) (×45)

Mites

These animals belong to the class Arachnida which is closely allied to insects. To this class also belong spiders, ticks and scorpions. They resemble insects in their small size, predominantly terrestrial in habits and in the possession of the same type of internal organs. They differ from insects in having four pairs of legs, no antennae, true jaws or compound eyes and in having only two body regions.

Out of the several families of this class, mites mostly [Tyroglyphidæ] are the ones which infest stored products and several other foods. When present in large numbers it is usually an indication that the grain or grain products in which they are feeding is high in moisture content (12 per cent or above) or going out of condition. Fortunately the mite species which attack grain are themselves sometimes attacked by predaceous mites, which may become so abundant as to kill the grain mites in comparatively short time.

There are a number of species of mites that infest grain and flour and other cereal products. They are all whitish in colour and so small (the largest being $\frac{1}{32}$ of an inch) as to be barely discernible to the naked eye. When they are abundant, some fine brownish powder accumulates over and within the infested materials and a musty and sweetish odour is given off which is quite characteristic of the mites. Occasionally a rather intense irritation of the skin is caused to workers who have been handling food products infested by mites.

Mites lay many eggs promiscuously on the food material. The young mites grow rapidly, being six-legged at first but eight legged on becoming adults. When conditions are unfavourable, they pass into a very inactive, non-feeding but very resistant stage. In this stage the body-wall hardens and suckers are formed on the underside with which they may attach themselves to other insects or mites. They may remain in this condition for a number of months without food but when conditions become favourable to their growth they moult and again become active. This peculiar adaptation enables them to survive for considerable periods and for this reason, premises once infested, are often difficult to clean up. They become more serious when grains are stored for a long time.

In regard to infestation by mites, moisture content of the materials plays a dominant role. Grains which have their skins in tact are immune from mite attack. But cracked skin of the grain allows the mite to penetrate them. Mite damage is sometimes restricted to certain parts of the products, e.g. in wheat the damage is confined to the embryo region. Indirect damage, such as heating, increase of moisture and the development of moulds have been reported to be the consequences of mite infestation. For the rapid multiplication of mites 18° C. to 25° C. is the optimum range of temperature.

Termites

Termites are popularly known as White ants. They are not true ants as those described above but they belong to a different class of insects. They resemble ants in their social and organized life. There are many local names such as 'demak' (Hindi), 'seonk' (Punjabi), 'ooli' (Bengali), 'ooli' (Ooriya), 'karayan' (Tamil), 'walawi' (Marathi) in different parts of India by which White ants are known. Termites are well-known for the ravages they cause to buildings and belongings of man in various parts of the world. Their main access to any food article or any other article having cellulose is always through cracks and crevices, to wood-work which they relish the most. They have particular liking for the cellulose contained in wood or any other vegetable matter.

Termites may live under the ground as sub-terranean individuals or in mounds above ground or insides wooden material. The ground dwelling termites comprise those species which build their colony either wholly in the ground or partly underground. The colony is started by a colonizing pair, which enters the earth or wood lying on the earth. The sub-terranean termites make their nests and runways from the nest under the ground and covered runways over exposed surfaces to enable them to reach the wooden structures in the buildings. The sub-terranean foraging tunnels may reach 50 yards to 200 yards from the actual nest. Their nests are not generally exposed and there is very little to indicate externally their habitat in the ground.

The mound-building termites can be easily distinguished by the White-ant hills which are generally found from 3 ft. to 6 ft. high near about neglected buildings or gardens, farms, on the bunds, etc. They also enter buildings through wood-work which generally comes into contact with the masonry work such as door frames, window frames, ventilators, etc. The nests of various groups of termites are laid in a diffused manner or regular concentrated tunnels are built. As pointed out above, a termite colony is generally started by a pair of winged adults, called the 'royal pair'. These forms emerge in large numbers from the parent nests especially after the rains. The emergence usually takes place in the evening and emerging adults get strongly attracted to light and after a brief flight they come to the ground and run about in pairs to find a suitable ground for

initiating a colony. The wings are said, the ground is excavated and the pair begins to live inside. Eggs are laid in a small batch are 6 to 12 in the first instance. They hatch into nymphs which take up the work of looking after the 'queen' for the first few days and in making the original cavity deeper and deeper so that the nest may become obscure from the external view. The 'queen' continues laying eggs from 4,000 to 80,000 eggs per day. Its abdomen enlarges due to development of eggs inside, as a result of which the 'queen' becomes absolutely immobile and inert. Her activity can be judged or perceived by slight movements of her antennae and faint ripples accompanying spasmodic expulsion of stream of eggs. The length of the abdomen is variable from an inch to even four to six inches. Normally the 'king' has got no function in the chamber or the cell but sometimes it works for the washing up of the few first hundred eggs laid by the female. The caste differentiation occurs early in life. The first born are the 'Workers' which are sterile, wingless and have soft bodies. Since they always live in the burrows or tunnels or earthen runways, they are generally pale dirty-white to light brown in colour. They do most of the work in the colony, such as excavating, procuring of food, caring and feeding of the young, etc. In some species of termites this caste is absent. The second caste is the 'soldier'. These forms are smaller than the workers but they are distinguished from the workers by their having large and strong jaws which are used for the defence of the colony when any danger is approaching or perceived. Their heads are highly chitinized, which give them protection from external attacks.

The only termites, that are found exposed, are the male and the female winged adults. Barring any accident or destruction of colony, the colony steadily grows inside and inhabits these nests for a number of years. In addition to water, six different varieties of food are consumed by termites. The principal variety, as mentioned above, is cellulose. This is because the termites can feed on cellulose as very few organisms can and that there is no other competitor for this food supply. Moreover, the termites are known to have in their intestines a large population of micro-organisms, bacteria, fungi and protozoa which assist in the digestion of cellulose. The termites have developed a system of mutual feeding with their saliva with regurgitated digested food and the rejected faecal matter. Their nests naturally develop fungi in various chambers and tunnels. In addition to these fungi, lichens and grass are also cultivated in the nests. All these organisms are so developed that they give an appearance of a garden and they are termed as Fungus gardens. The termites maintain the atmosphere of the colony at such humidity that these gardens can flourish well. The workers are capable of travelling long distances through sub-terranean gallaries in search of their food and therefore they attack all store materials, e.g. wooden planks, papers, etc. lying in dark and moist buildings.

(vi) Rats

Rats like insects are greatly responsible for heavy losses to stored grain. They not only eat and contaminate human food but spread and transmit many serious diseases also. They start damaging grain when it is maturing in the field and continue their attack in all stages of storage and processing till it is ultimately consumed. Rats spoil more grain than they actually eat. They enter the stores in darkness, gnaw at the bags, spill the grain and carry some of it back into their burrows. On a conservative estimate, they are responsible for an annual loss of about one million ton of food and seedgrains.

There are a number of species of rats in India the most common being the 'Black rat' (*Rattus rattus*) and the 'Brown rat' (*Rattus norvegicus*). Sometimes the 'House mouse' (*Mus dubius* and 'Indian mole rat' (*Gunomys kok*) also cause damage in farm stores. The Brown rat is of a heavy build and has small, thick ears and its tail is shorter than the body and head. The body and ears are covered with coarse fur. It usually lives in extensive underground burrows which are usually situated at a depth of a foot or so below the level of the floor. It may also live in the lower part of the walls and in sewers. The Black rat is smaller than the Brown rat. It has thin, translucent ears, smooth fur and a thin tail which is longer than the body and head. It is an expert climber and

prefers to live in the roofs of buildings or among the branches of trees. These rats cannot jump more than 30 in. and stretch beyond 8 in. Mole rats are usually found in the fields but sometimes attack granaries also. They generally live in burrows in the field bunds or in the drains.

Rats are prolific breeders. They start breeding when three to four months old. With sufficient food available, they breed very rapidly throughout the year. The gestation period is 10 weeks only. A single female produces in one year on an average 8 to 10 litters each containing about 9 young ones, the total number of progeny being 800.

Though rats may not be seen moving about in stores or their vicinity but the following will give clue to their presence :

(i) Loose earth, heaped up near a wall, indicating that the rats have burrowed a fresh hole.

(ii) Shiny droppings lying about the stores. Moist ones will indicate fresh infestation. Droppings of the Black rats are usually seen scattered whereas those of the Brown rat will be in small groups near the nest.

(iii) Marks of feet and tail left on dusty floor.

(iv) Greasy marks on wooden beams which rats generally leave when climbing them.

(v) Bags gnawed at with grain spilled out on the floor.

(vi) Presence of irregular holes in the doors and windows, etc. gnawed out by rats.

Experience has shown that the probable rat infestation is always higher than what is superficially evident in grain stores.

(v) Fungi and Moulds

Fungi play an important part in the deterioration of grain while in storage. The grain, after harvest, carries a number of spores of various saprophytic fungi on or in itself. As many as 57,000 spores have been reported to be found on a single grain. If the grain is moist when placed in storage or it subsequently becomes moist, the fungus spores germinate and the fungi attack the grain kernel. The inevitable result is heating of the grain which is rendered unfit for food, seed or even for animal feed.

Fungi commonly attacking stored grain, are species of *Aspergillus Penicillium, Fusarium.*

F

II. SOURCES AND DEVELOPMENT OF INFESTATION IN STORES

(1) General

The two factors which directly influence rapid pest multiplication are temperature and humidity. Insect development is most rapid when the two factors combine. When food and moisture are favourable, temperature is the chief single factor affecting the activity and multiplication of insects. On the other hand when temperature is favourable, moisture is the chief solitary factor affecting the progress of weevil infestation. Insects obtain the moisture necessary for their life from their food. They also produce moisture as a product of their metabolism.

Store insects are able to live and carry on life activities through a considerable range of temperature. Most of them succumb if exposed for sometime to a temperature of 120°F. A few species like *Rhizopertha dominica* can tolerate temperatures some degrees above this point. The exact range varies with different life-stages. Temperatures below 55°F. retard pest activities, but store insects on the whole are much more tolerant of low temperatures than of higher ones.

The insect pests of stored grain are, for the most part, of sub-tropical origin and generally do not hibernate in India. Insects like *Tenebroides mauritanicus*. *Trogoderma granaria* may hibernate and thus pass over very long adverse periods.

Similarly insects within the grain itself are rarely exposed to extremes of temperatures, as grain is a poor conductor of heat. In an empty store, similar conditions are available in cracks and crevices and in other situations behind the plaster, etc. to which some left-over insects migrate and tide over the period of short supply of food. They feed on farinaceous materials accumulated in such places. Frequent changes in temperature do not allow insects to establish their colonies and breed therein.

The effect of humidity is almost intimately associated with that of temperature and humidity operates indirectly through the moisture content of the grain. Humidity affects the longevity of various store insects. In fact the length of different stages of store pests depends mainly on temperature and humidity conditions of the store and the stored grain. The life-cycle as for instance of 'khapra' or *T. mauritanicus* may be completed in as many as 30 days under optimum conditions of temperature and humidity but under adverse conditions it may take even three years.

The moisture content of grain depends upon the relative humidity of the atmosphere, since grain moisture in due course tends to come into equilibrium with the moisture in the air. Thus the amount of moisture in grain fluctuates in sympathy with changes in the temperature and relative humidity of the air. The rate at which the grain will lose or gain moisture content will depend upon the extent to which it is freely exposed to the air. On this will, also, depend the increase in insect infestation.

Pest infestation is rapid above 75°F. and 75 per cent relative humidity at which the moisture content is generally in the neighbourhood of 14 per cent. In fact insect infestation will tend to increase with every increase in moisture content above 10 per cent or so. If the relative humidity is high and temperature is low, the increase of one per cent may take place in a day. A moisture content below 10 per cent, is sometimes not adequate for the normal activity of insects. This upsets the normal metabolic functions of the insects. It will be evident that the period of survival and the effect of the adverse conditions on insects will depend upon the temperature and degree of dryness. Every degree of increase in temperature will correspondingly bring about a drop in the relative humidity. It is, therefore, essential that grain intended for storage over long periods should have moisture content less than about 8 per cent.

Proper appreciation and understanding of such factors as the life-histories of major grain pests at different temperatures and in grain of different moisture contents, changes in grain when exposed to varying environmental conditions, the degree to which different method of storage permit or prevent these changes and climatic conditions in different localities, are of great help in deciding when, where and how to store grain that may have to be stored for long periods of time.

It is a well-known fact that damp grain stored is liable to heat and rapid deterioration. This is due to the respiration of grain. During respiration the grain takes in, as in normal respiration, oxygen which oxidizes certain substances constituting the grain, particularly the sugars in the embryo region. As a result of oxidation, water and carbon dioxide are produced from the grain cells. During these processes heat is generated, and the grain is said to 'heat', which increases with the increase in the rate of respiration.

The increase in the rate of respiration is gradual and fairly uniform until moisture content exceeds 14 per cent. Density of the grain kernel and the higher ratio of the germ to endosperm affects the rate of respiration. The soft variety respires more rapidly than hard with the same moisture content. Shrivelled grain are known to respire two to three times more than the sound and plump grain at a moisture content of 14 per cent. This is believed to be due to the higher ratio of the germ to the endosperm. The period for which grain has excess of moisture bears a direct relation to the rate of respiration. A corresponding increase in the temperature accelerates the rate of respiration until 130°F. is reached, with which the presence of oxygen in the air surrounding the grain is correlated.

The size of inter-spaces between the bags of grain and between the grains is variable. The volume of such spaces varies according to the compactness and looseness of the bags in a stack. The volume between the grain is taken to be nearly 40 per cent of the actual space occupied by the grain. The air in spaces between the outer bags in a stack is directly influenced by changes in the temperature and humidity of air surrounding the stack which is naturally variable on different sides of the stack, depending upon the degree of exposure to sun and wind. In a compactly built stack, the temperature, humidity and carbon dioxide content of the air in these spaces are largely determined by the temperature, moisture content and respiration of the grain.

Abundance of insects can be determined by the prevailing temperature and humidity. Areas which have equitable climate, e.g. coastal areas, have continuous insect activity throughout the year. Insect activity is correspondingly slow in areas with extremes of temperatures, when natural mortality may also be high.

Insect damage to grain may be grouped in the following categories :

(a) *Loss in weight*

Grains eaten by insects obviously will result in the reduction in weight. This type of loss under normal condition of trade storage is generally made up to some extent by moisture absorption. The grain may pick up the moisture under ordinary storage conditions or the grain may be made moist by trade manipulations. That is why trade people do not show any loss due to the reduction in weight by insects. In areas of high humidities, stored grain will show gain in weight. The exact degree of gain in weight will, therefore, depend upon the prevailing humidity and the duration of storage period.

(b) *Reduction in nutritive value and palatability of grain*

Loss in the nutritive value and palatability of the grain and grain products brought about by insects is seldom realized. Most insects attack cereals at the embryo or germ point of the grain which is the most nutritious part of the grain. Flour made of the grain damaged at this point will not be so nutritive as the flour made from a sound grain. Mites impart strong odour and a taint to the material they infest. This odour and the taint are liable to persist up to the finished cooked product. It is on account of this that millers generally do not accept mite infested grain. From flour infested with mites one cannot prepare good bread.

In case of heavy infestation the flour has a sour taste, and the product is not only unpalatable to humans but to the animals as well.

(c) *Loss of grain stocks*

Heavily infested stocks have sometimes to be destroyed or those, originally intended for human consumption have to be used for starch manufacture, animal feeding, tc. Pests like *Plodia interpunctella*, *Corcyra cephalonica*, etc., eat less than what they spoil by webbings.

(d) *Change in the appearance of the foodgrain and their products*

Insect infestation changes the original appearance of grain. Unmilled cereals infested with *Sitophilus oryza* and *Sitotroga cerealella* and pulses attacked by Bruchids will often be seen riddled with exit holes. *Tribolium castaneum*, besides imparting offensive smell, gives a yellowish green taint to the flour which even animals refuse to take.

(e) *Damage to receptacles and mills*

Heavy insect infestations damage gunny fibres and weaken them as a result of which the bags might collapse and the grain is spilled. This is specially true of insects such as *Plodia interpunctella*, *Gibbium psylloides* or cockroaches which deposit large number of cocoons on bags and weaken them. Insects like *Rhizopertha dominica*, *Tenebroides mauritanicus*, in the absence of food in a store, bore into the woodwork both for pupation and tiding over the unfavourable period. In cases of very heavy infestation, these insects may so weaken the structure that building may stand in danger of collapse. Infestation by termites may bring about collapse earlier than by other insects mentioned above.

Webbings of *Ephestia cautella* generally get collected in the spouts of mills, eventually leading to complete stoppage of the mills. This necessitates complete overhauling of the machinery.

T. mauritanicus has the habit of cutting silk-net cloth in bolting reels and redressing machine in flour mills. They may also burrow into the woodwork of the mills which, in order to eradicate the pest have to be stopped periodically. This affects the ultimate cost of processing, which the miller has to increase to make up the loss suffered through stoppage of mill work.

(f) *Loss due to screening*

Serious insect infestation necessitates the screening of stocks. As a result of this mechanical operation a certain amount of grain is inevitably lost. In the case of webbed materials, the loss is much more than is usually estimated.

(g) *Loss of goodwill*

This loss is more of a psychological nature. Constant supply of infested stuff from any concern or institution would inevitably result in the loss of its prestige. Consumers will stop taking any supply from such firms.

(h) *Possible injury to humans or animals resulting from the consumption or handling of infested food stuff*

Food stuffs infested with mites or *Tribolium spp.* are known to cause digestive disturbances. Soysa and Jayawardena [1945] report that such food grain may cause pulmonary troubles among workers in infested ware-houses. Certain species of mites also cause dermititis to labourers. Dermititis may also result by irritation from the cast skins of *Trogoderma granaria*.

(ii) SOURCES OF INFESTATION

There are quite a number of people who still think that the appearance of insects in stored grain is spontaneous and is a necessary evil. It need hardly be emphasized that insect infestation of grain are the direct result of egg-laying by insects which are already present in the godown o

enter it along with the grain. Thus, if insects do not gain access to the grain it will remain free from infestation. The following are the main sources of insect infestation :—

(i) Some insects like *Sitophilus*, *Sitotroga* or Bruchids fly from the nearby farms or cultivator's stores and start laying eggs on the maturing grain. They are generally laid on the heads of the grain. Appearance of these insects in the field depends mostly on weather conditions. Most of the eggs survive the thrashing operations and reach the store with the grain. Under favourable conditions eggs hatch and the larvae start feeding on the grain.

(ii) Generally when stores are emptied some insects are left behind. They live on spilled grain or on farinaceous materials which remain accumulated in cracks and crevices. These insects thus continue growing and breeding. It is often seen that in the rush of work or heavy handling and rapid movement of grain, the cleaning of stores is not properly done or ignored altogether and the fresh stocks are put in such unclean infested stores. The obvious result is that insects present in the old grain or accumulated in cracks and crevices or in spaces in the door frames, start coming out and quickly contaminate the new and fresh stocks. When the owner finds his stocks thus contaminated, he believes that insect appearance is spontaneous. Sometimes, it so happens that the fresh stocks are placed by the side of the infested stocks. Insects from the infested stock migrate to the fresh ones and cross-infestation takes place resulting in the contamination of the entire stock.

(iii) Insects especially the 'khapra' larvae remain lodged in the meshes and seams of bags when they are emptied of the grain. These infested bags are rolled up and often placed without cleaning in store rooms. The insects continue feeding on any farinaceous material which remains sticking to the bags. When these bags are filled up with new grain, the insects start infesting it at once.

(iv) Railway wagons, lorries, or trucks, which are used to carry grain, constitute an important source of grain infestation. This is evident from the fact that on many occasions, uninfested commodities transported from one centre have been found thoroughly strewn with insects at the other end during the course even of a fortnight. Insects remain lodged in cracks and crevices that trucks and wagons have in large numbers and keep on breeding on some left-over farinaceous material.

It has often been seen that stores holding grain, to all appearances, look free from insects. Besides the examination of cracks and crevices, seams and meshes of bags, the following features in a store would also indicate the presence of insects :—

(1) The presence of webbing over the walls, ceiling and even on the surface of grain if it is in bulk. This would indicate the presence of the Indian meal moth, *Ephestia* or even the Rice moth.

(2) Presence of grain kernels with the germ, injured or completely removed.

(3) Presence of white patches of farinaceous material on bags ; the more the number of such patches, the higher the degree of infestation. In serious infestations large patches will also be found on the floor at the base of the stacks.

(4) Patches of discoloured and tough grain on the surface of a bin often indicate mite infestation in addition to insects.

III. TYPES OF STORAGE OF FOOD AND SEED GRAINS

Grains may be stored in bulk or in bags. Though bulk storage should be preferred to bag storage, the latter method is more common because it is more convenient for handling. The two types are discussed below :

(i) Bulk storage

Bulk storage will be advantageous particularly for wheat, gram, paddy, barley, maize, etc. Apart from the advantage that grain stored in bulk is more safe from attacks by insects, rodents and from the effects of climate, the grain, if received, in infested condition can be fumigated *in situ* and further damage can be prevented. There is also obvious economy as the cost of gunnies and twines is avoided. After bulking out the grain, the gunnies can be used for fresh supplies. These bags can be fumigated or steamheated to kill any insects that might be lodging in their seams and meshes. Thus, a check on the spread of infestation can be effected. In addition, bulk storage saves time and labour, avoids waste from leaky bags, promotes comparative ease and accuracy of inspection, and facilitates the conditioning of grain. If grain is stored in suitably designed bins, bulk storage will permit separation of different grains from one another, different grades of one particular grain, new from the old, damp from the dry, etc.

It must be mentioned that, if full advantage of bulk storage is desired, the grain should be dry and free from infestation. Equally important is the fact, that the stores or bins should be damp-proof and uninfested. If these conditions are secured, grain can be stored in bulk for long periods without any chance of its deteriorating.

Various types of receptacles in use with the cultivators, merchants, and those on farms both private and under Government management are described below :

(*a*) **Khattis**

Where the sub-soil water is low, underground cellars known as 'khattis' are used for storage of foodgrain. A 'khatti', is an underground pit with a narrow circular opening at the top, about $2\frac{1}{2}$ ft. in diameter, through which a man can pass. It is usually 15 ft. to $16\frac{1}{2}$ ft. deep and about the same in diameter and can usually take 600 to 800 maunds of grain. Such a 'khatti' is said to cost about Rs. 20 only.

Generally wheat, barley, peas, gram and maize are stored in 'khattis'. This method of storage is extremely cheap. A 'khatti', once made, is serviceable for years. In some parts of the United Provinces where this method is prevalent, 'khattis' as old as 100 years have been observed.

Before putting in the grain, a layer of 'bhoosa' is placed at the bottom, and against the walls of the 'khatti'. When it is full, its mouth is closed with 'bhoosa' and plastered with mud in flush with the surface of the ground. For taking out the grain, a man goes down into the 'khatti' with a basket, which is pulled up by means of two thick ropes at opposite ends on the rim of the basket (Fig. P).

The most serious defect of the prevalent 'khatti' system of storage is that the grain absorbs moisture from the walls and turns black and becomes unfit for human consumption. On account of the absorption of moisture, there is often an increase (about 1 to 3 per cent.) in weight of the stored grain, depending upon the moisture condition of the soil of the area.

Thus the efficiency of a 'khatti' depends on (*a*) the kind of soil in which it happens to be dug (*b*) its age, and (*c*) its size. One made on high ground is naturally always better. With age a 'khatti' seems to become drier and, therefore, less grain is spoiled in it but, it is reported, that the top layers are still liable to insect attack. In large 'khattis', capable of holding 1,500 to 2,000

maunds, the insect damage is comparatively small on account of the larger bulk of the grain. But, as it is easier to get customers for small quantities, the dealers of ordinary means prefer 'khattis' of smaller capacity. The exporters prefer larger ones.

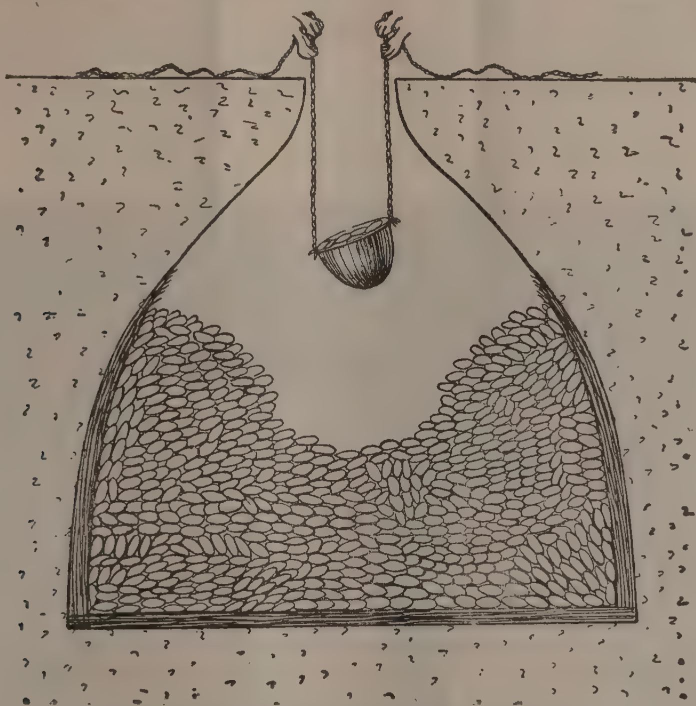


FIG. P. Removing grain from a storage pit 'khatti'

'Khattis' may be said to occupy, in a way, the same position in India as the country elevators in the United States of America, Canada, etc. 'Khattis' are built in large grain centres where the farmers bring their produce for sale. The dealers store the grain in them and the grain thus stored may pass through several hands before being actually emptied out and consumed. The grain stored in 'khattis' (at least wheat) does not seem to lose its germinating power.

The 'banda' is a modification of the 'khatti' as is evident from the illustration (Fig. Q). It is about 15 ft. deep. After filling it, the grain is sometimes heaped up at the top and covered with a layer of mud. The convex covering does not allow the rain water to get in. 'Bandas' are made on high ground and sometimes have masonry walls and bottom. They are common in the Central Provinces, e.g. in districts of Jubbulpore, Saugor, etc. In 'bandas', as in 'khattis' the stored grain absorbs moisture and acquires a slight smell due to fermentation.

The 'pev' of the Desh or Ghat Districts (Sholapur, Satara, Poona, Ahmednagar, etc.) of the Deccan is a huge underground godown meant for storing very large quantities (hundreds of tons) of 'jowar' and 'bajra' grain. In principle it is similar to 'khattis'. It has small square or circular openings at the top which are made at some depth below the ground level. After filling the 'pev' and closing the openings, the earth is filled up and the place is marked with some permanent sign to indicate the position of the openings.

'Targhars' are underground cellars provided with lid-like doors. In such stores also grain is reported to absorb moisture and acquire a slight smell due to fermentation.

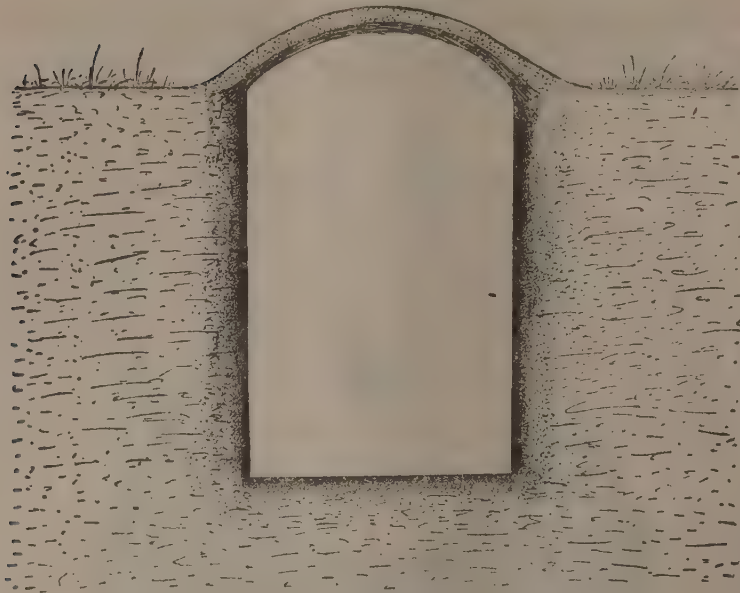


FIG. Q. Storage pit 'banda' of Jubbulpore

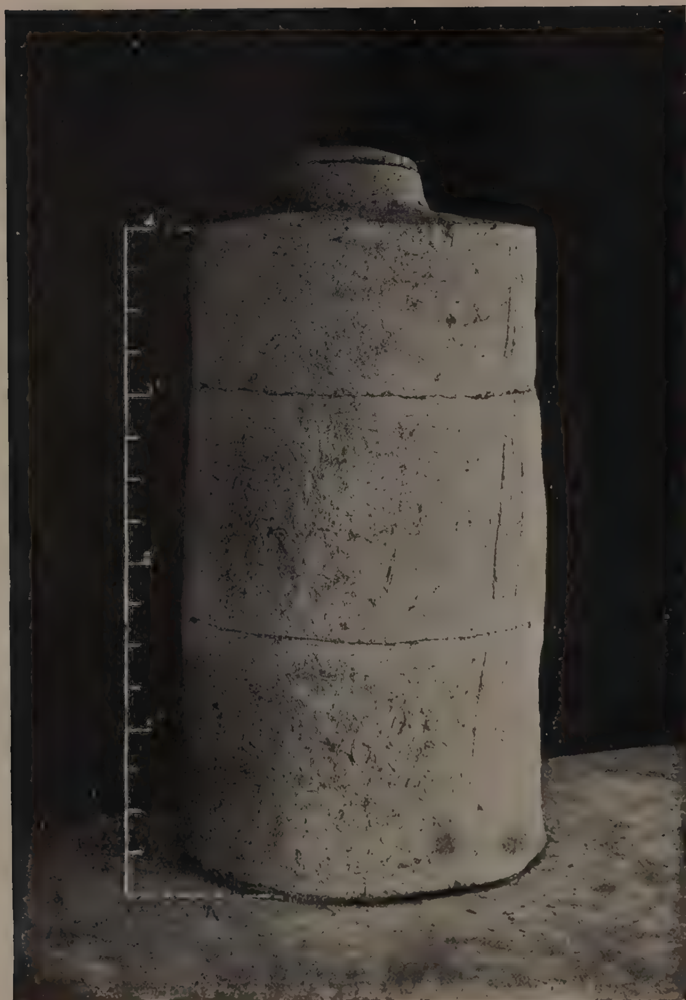
In Rajputana area structures known as 'khas' or 'khais' are in use. The grain is said to keep in sound condition in such receptacles for considerable periods. Underground 'khas' or 'khais' are on the pattern of a well. The inside is lined with stone and plastered with mud or cement. These structures are usually 20 ft. deep and 12 ft. in diameter. Diameter is uniform up to three-fourths of the height of the 'khais' whence it gradually narrows up to the manhole which is 2 ft. to 3 ft. in diameter. This is rimmed with about two or three inches thick ridge of mud. Rectangular pieces of stone slabs are spirally fixed inside to serve as steps for getting into the 'khas'. Grain is filled in from the top. When the 'khas' is full, a layer of sand or road-dust or 'bhoosa' is given on the top after which the 'khas' is closed with a circular stone-slab made to the size of the manhole and sealed down to the rim with mud. 'Khais' are also found in rectangular shapes, approximately measuring 18 ft. × 19 ft. × 8 ft. Steps of stone slabs are provided on one side of the wall up to about two feet above the floor. The grain is taken out by means of buckets as is done in the case of all underground 'pits'.

The 'khas' or 'khais' above the ground surface are on the pattern of a water tank having thick stone walls lined inside either with mud or cement plaster. It is of uniform diameter up to about three-fourths of its height, whence it gradually narrows up to a manhole 2 ft. to 3 ft. in diameter. These are also provided with steps of stone slabs spirally arranged as in the underground structures. Dimensions are also the same as in the case of the underground pits although they vary from place to place. The grain is filled through the manholes and is taken out from an opening provided near the bottom. This opening is kept closed when the 'khas' is full. Capacities of various types of 'khas' or 'khais' vary between 1,000 and 1,500 maunds of grain.

During the past 18 years 'pucca khattis' have been constructed by rich merchants at some places. Each 'khatti' is 10 ft. × 10 ft. × 8 ft. with a man-hole 2 ft. × 2 ft. covered by steel iron lid. It is capable of holding nearly 500 maunds of grain and costs about Rs. 300*. The obvious advantages offered by these concrete 'khattis' are complete protection from insects, rats and dampness, so that the grain can be stored with safety for long periods. The practice of storing grains in such structures is also being adopted by Government Farms.

* Pre-war cost

Small storage receptacles, called 'kothis' and made of unburnt clay. The large (to left) is about 30 in. high and is made of two pieces, one set over the other and is provided at the lower part with a hole for taking out the stored grain. The smaller one (to right) is about 20 in. high—common in Bihar



Storage receptacle, 'kothi', made, in three pieces, of unburnt clay. Inside measurements, 4 ft. high and 2 ft. in diameter—common in Bihar

(b) Mud bins

They are either oval, square or oblong. Sometimes they are dome-shaped or even chimney shaped. 'Bins' are made of unburnt clay, which is mixed with bits of straw, dry grass, some common local weed, to give it a tough consistency. The walls are generally 1 in. to 1·5 in. thick and the entire wall is not built all at once but is gradually added on to the lower portion as it gets dry.

In Bihar, mud bins or 'kothis' (Plate IX) are oval in outline, with a small circular hole slightly above the base of the bin, through which the stored grain can be taken out without opening the mouth at the top. The cover or lid is of the same material as the walls, and is circular in outline. After the grain has been put in, the lid is plastered with mud to seal the store. 'Kothis' may contain one, two or three pieces (Plates IX and X). The different pieces are placed above one another and prevented from slipping off by means of projecting rims which interlock into one another. Square and oblong 'kothis' are also made and frequently they consist of several chambers. Due to having so many joints and crevices, it is very difficult to make them insect-proof. In the Punjab, 'kothis' are invariably square or oblong in shape (Fig. R).

First, clay is shaped into a small rectangle and allowed to dry. This is just like a thick clay slab. It is placed and plastered on to four (one on each corner), six or sometimes 12 (three on each side) pillars, about a foot high and about 6 in. in diameter, also made of unburnt clay. On the slab as the base, walls are raised bit by bit as described above in the case of the Bihar 'kothi'. Usually the walls are 2 to 3 in. thick and are raised up to a height of 6 to 7 ft., depending on the space available inside the house. The open mouth at the top is covered by a clay slab similar to the base. On one side, the future front side, there is a small door provided with hasp and staples, so that it can be shut or opened when required. In the case of large 'kothis' there may be two doors. A small circular hole is provided near the top and a similar hole near the base through which grain is taken out when required without opening the door.

FIG. R. 'Kothis' constructed of mud used in the Punjab for storing grains

The grain is poured into a 'kothi' through the door and when it reaches the door level, the door is shut and it is poured from the upper hole or the mouth at the top. 'Kothis' are of varying capacities, from 50 to 200 md. or even more. The grain stored in a 'kothi' does not remain, free from insect attack for more than a season or so.

There is another type of mud bin called 'bharolis' in use in some parts of the Punjab, especially where holdings are small and grain is required for day-to-day use. 'Bharolis' are generally about 3 ft. high and the method of their construction is the same as that of a 'kothi'. They are of different shapes in the various parts of the Punjab (Fig. S).

In some parts of the Punjab, chimney-shaped 'bharolis' (Fig. T) are called 'bharolas' and are provided with a small door a little above the middle.

FIG. S. Different types of 'bharolis' used in the Punjab

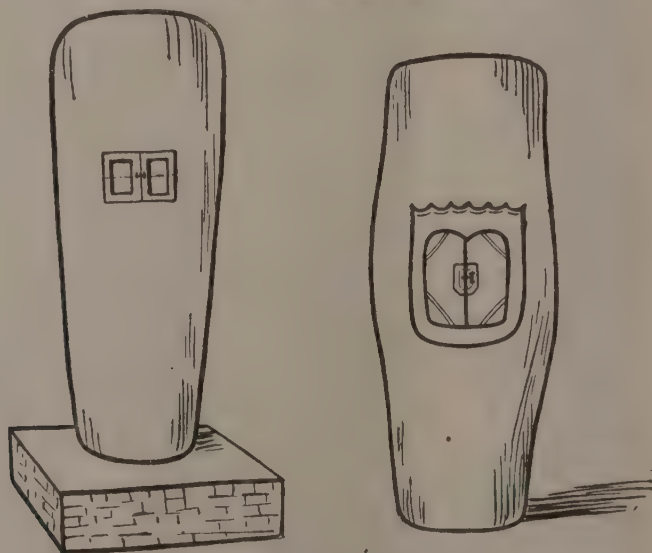


FIG. T. 'Bharolas' used in some parts of the Punjab

In the central Punjab, a receptacle called 'petti' (Fig. U) is also used. It is made o[f] unburnt pond clay and in shape resembles a box. It is sometimes partitioned into two chambers. The lid consists of a big slab made of clay and has two small circular holes, one opening into each chamber. The chambers are provided each with a small circular opening at the base for taking out the grain. The lid can be sealed down with mud when the grain is not required for some time. The lower holes are usually kept plugged. It is usually 4 ft. × 2½ ft. × 2 ft. in size.

(c) 'Pucca' bins

In some districts of the Punjab, eg ; Gurdaspur, 'pucca' cemented 'kothis', oblong in shap[e] are commonly used (Fig. V). Their capacity is 100 md. to 300 md. and the grain stored therei[n] remains safe for more than two seasons. Occassional sunning of the grain after the rains ma[y]

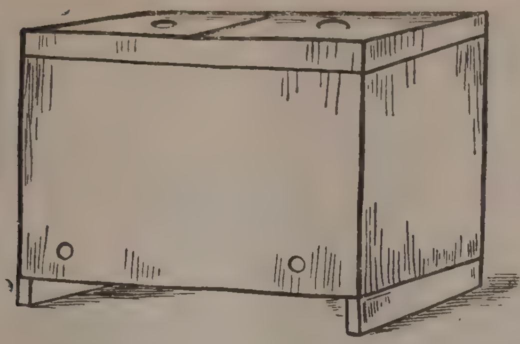


FIG. U. 'Petti' used in the Amritsar District, Punjab

further keep it free from insect attack for another season. Such ' kothis ' have a serious defect in that their proper cleaning is rather difficult, if not impossible. This allows the carry-over of some insects, which in due course increase in numbers. 'Pucca' cemented 'kothis' are used by landowners or 'zamindars', with large holdings otherwise mud 'kothis' are prevalent as in other parts of the Punjab.

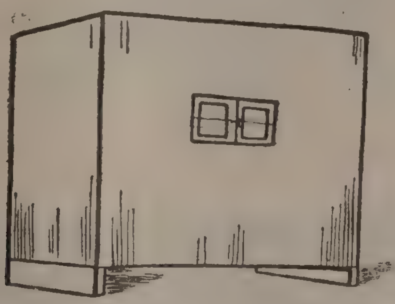


FIG. V. 'Pucca kothi' used in some parts of the Punjab

In some parts of the Punjab a wall 4 ft. to 6 ft. high is made on one side, across a living room in the house. The chamber, thus formed, is further divided into two or three or even more compartments by means of partitions. The compartments thus formed are termed ' bukharis ' (Fig. W). Grain is stored in loose heaps in ' bukharis ' and is often covered with coarse sand. Generally the capacity of a ' bukhari ' is about 200 md.

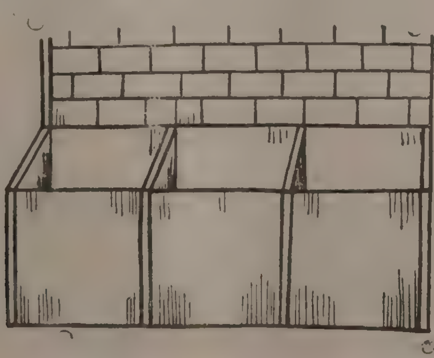


FIG. W. 'Bukhari' as used in the Punjab

In certain districts (e.g. Ferozepore) of the central Punjab, 'bukharis' are circular tank-like structures made of 'pucca' masonry work (Fig. X). They are generally kept in the courtyard of the house under some sort of covering against rain and grain is taken out for day-to-day use. They are about 5 to 6 ft. in height and about 4 ft. in diameter. The stored grain is kept covered with red sand over which some thick, coarse cloth is spread. A small circular opening is provided near the base through which grain can be taken out when required. Usually it can contain about 100 md. of grain (gram and wheat). The grain stored thus is reported to remain free from insect attack for about two seasons.

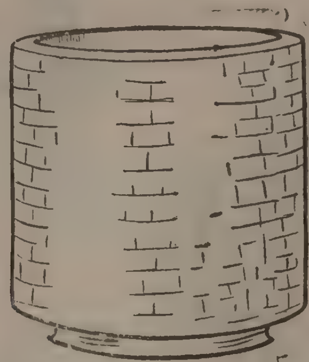


FIG. X. Circular 'bukhari' as used in some parts of Ferozepore District (Punjab)

In Bihar, outdoor granaries of various shapes, called 'bukharis' (Plate XI, fig. 1), are built on a raised platform in order to avoid dampness. The walls of a round 'bukhari' (Plate XII. figs. 1 and 2) are usually made of the stems of 'ikri' (*Saccharum fuscum*) plastered together with mud. It has four chambers with a door for each. The walls are of wattled bamboo, plastered over with mud. In Plate XIII, fig. 1, right hand side, part of such a 'bukhari' in the finished condition is seen. On the left side there is a 'bukhari' with masonry walls, with open arches below for the prevention of damp. It has three chambers as is evident from the three doors. Wheat, barley, maize, paddy, peas, etc. are stored in such 'bukharis' with plenty of 'bhoosa' all round the grain, as is shown diagrammatically in (Fig. Y). Sometimes gunny bags, filled with grain, are similarly kept in the midst of 'bhoosa' which is well pressed to make it as impervious to insects as possible. Wheat is said to have remained free from insect attack, in this manner, for two or three years Similar structures called 'gadi' are used for storing paddy in the West Godhavri District of Madras.

(d) Straw bins

Bins made entirely of straw are in common use in Bengal for storing indoors 4 md. to 16 md. of rice or unhusked paddy grains. They are called 'puras' (Plate XIII, fig. 2 and fig. Z). The hollow space inside is used for storing grain and there is a thick lining of straw between the grain and the walls. Unhusked paddy grains are known to keep well in 'puras' for years. Husked rice is, however, known to be attacked by the Rice weevil (*Sitophilus oryza*) if kept for two or three years.

There is another method of preserving paddy inside straw bundles. The grains are placed in loose straw which is then rolled up into a large bale which is tightly secured by means of ropes passed round it. In Bihar and Orissa these bundles are also known as 'puras'. They are either kept indoors or in the courtyard where they are covered with earth. Sometimes several such 'puras' are kept outside (Plate XI, fig. 1), similarly covered with earth, on a platform, the covering of earth being intended to protect the grain from rain. A similar method is reported to have been followed in the Konkan where the bundles are known as 'mudhas' or 'muras'. About 2 md. of grain can be stored in one bundle. Grain layers next to the surface of the structures are sometimes affected by moisture.

FIG. 1. Two 'bukharis' for storage of grain. Two 'puras' of paddy seeds are seen lying on the ground between the 'bukharis'

FIG. 2. A glass jar, 12 in. high and $4\frac{1}{2}$ in. diameter, and two earthenware receptacles called 'harias' with covers. The larger one is about 13 in. high and about 14 in. in diameter, the smaller one about 6 in. high and 7 in. in diameter

FIG. 1. A 'bukhari' under construction and almost completed. The walls, of bamboo wattling, have not yet been plastered with mud

FIG. 2. Two 'bukharis' of a type common in Bihar for storage of grain

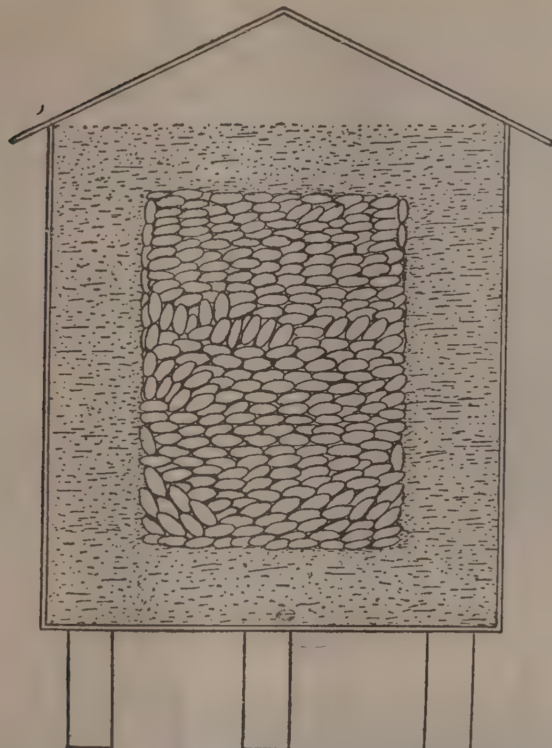
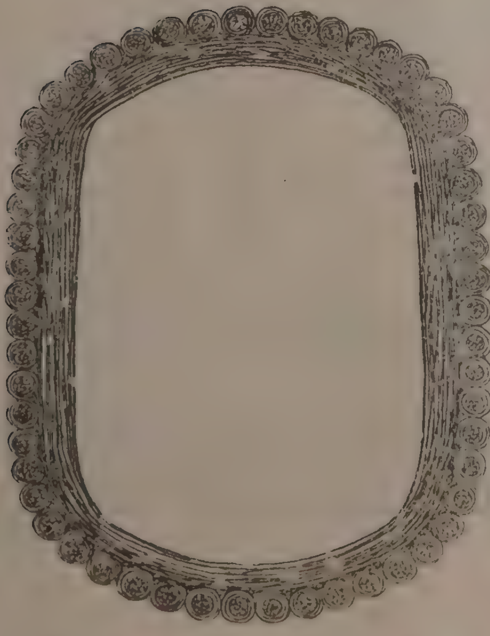


FIG. Y. Section through 'bukkhari' as used in Bihar, to show how the grain is stored with 'bhoosa' (chaff) all round it



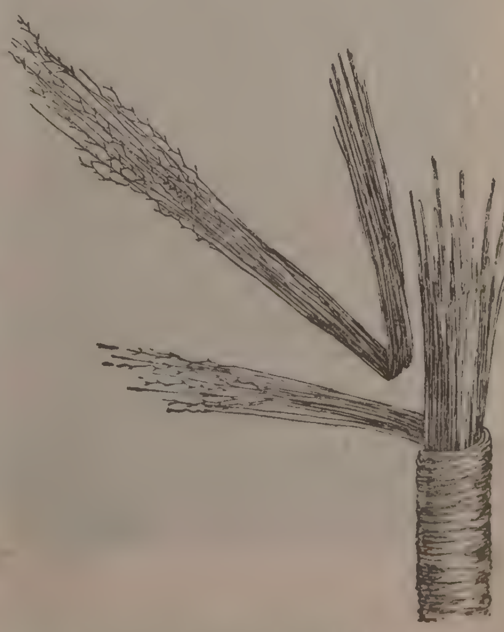


FIG. Z. Section through straw 'pura' Preparation of a straw rope showing how the rope is fed with straw

In western Bengal straw bins 'morai' (Plate XIV and Fig. AA) are generally used for storing paddy grains in bulk out of doors. A 'morai' is built with ropes of straw practically in the same way as the straw 'pura' in use in Bihar. A large 'morai' intended for keeping a large quantity of grain is usually built on a solid platform made either of earth or masonry. First, a thick layer of straw is spread on the platform on which some grain is poured, and around the grain 'morai' is gradually built. The lowest ring is made of very thick rope and is quite distinct from the upper ring. It helps to keep the straw intended for lining stand erect. More grain is poured in and the rope is taken round and round. The top is covered with a conical thick and rain-proof thatched roof.

A 'morai' having a capacity of about 500 md. can be built in the course of a single day by two or three men. The 'morai' is a cheap, efficient and convenient method of storing paddy. With little care a 'morai' lasts for seven to eight years, even when used frequently. Paddy grains are known to remain safe from insects in 'morais'. But layers of grain next to the surface of the 'morai' sometimes get affected by moisture.

A receptacle, similar to the 'morai' is also found in some parts of the Western and Central Punjab. This is called 'kup' or 'kupi' or 'musal' and has a capacity of about 100 md. This structure is also mainly for outdoor storage. It differs from the 'morai' in being entirely dome-shaped and having the encircling rope not so closely wound round it. Like the 'morai' it is built on a platform and made in about the same way as the 'morai'. Similar structures called 'pattarai' are used for storing paddy in Tanjore District of Madras.

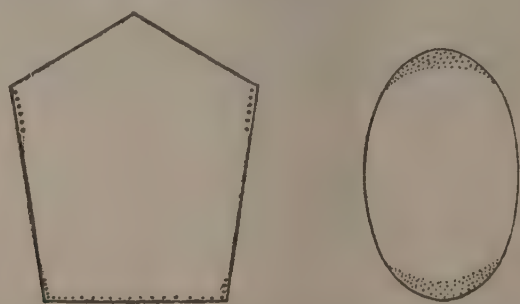


FIG. AA. Showing diagrammatically by dots where grain is affected when stored in a 'morai' (left) or 'pura' (right)

In some parts of the Punjab, especially the western districts, structures known as 'pallas' or 'paili' are in use. A small round platform about a foot high is built on which wheat straw is spread. A fairly big rectangular piece of palm leaf or 'sarkanda' mattress is rolled round the platform and tied with a rope keeping it slightly above the ground. The edges of the mattress are then stitched together (Fig. BB). Into this drum-like structure grain is poured. When full, it is covered with another piece of mattress. Sometimes the mattress is strengthened by plastering it with mud. In some parts of the Hoshiarpur district deep 'iron' pans are used in place of the platform.

'Pallas' are usually of 5 md. to 50 md. capacity. Grains stored in *pallas* are reported to remain in excellent condition even for more than two or three seasons, probably due to the fact that the grain is always partly exposed to the free air through the chinks and crevices of the mattress.

(*e*) **Bamboo bins, etc.**

Bins made of bamboo matting or wattling stems of *Saccharum arundinaceum*, or sticks of some leguminous plants, etc. are found in some parts of Bengal, Assam, and the Deccan. They resemble ordinary cylindrical iron bins in appearance. Their walls are plastered with cowdung both inside and outside or only inside and usually they have similarly plastered solid bottoms. They are, as a

FIG. 1. A 'bukhari' with masonry walls. On the right hand is also seen part of another 'bukhari' with walls of bamboo wattling plastered over with mud

FIG. 2. 'Pura' made of straw rope

FIG. 1. A 'morai' in process of building

FIG. 2. A completed 'morai'

rule, used for indoor storage and sometimes have conical umbrella like coverings which can be placed on the top. In some places they possess no base as such but are pitched on an ordinary floor and made firm by means of sticks driven into the ground. In such cases they are used for rather coarse stuff like unhusked paddy grain. It may be remarked that such bins are incapable of keeping out insects even when well-plastered with mud.

FIG. BB. 'Palli' for preserving grains

In some parts of the Punjab, e.g. Rohtak and Amritsar Districts, receptacles made of gunny cloth called 'thekas' or 'thekis' are in use (Fig. CC). They are oblong in shape and much

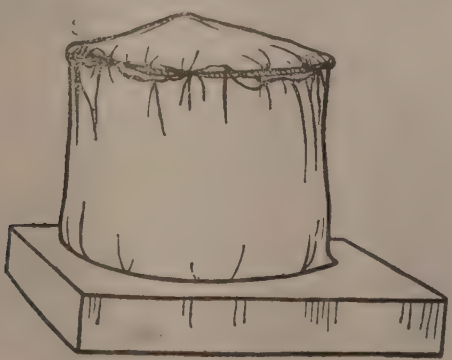


FIG. CC. 'Thekas' or 'thekis' for preserving grains

bigger than the ordinary bags. They are 4 ft. to 6 ft. in diameter and 4 ft. to 7 ft. in height and can hold up to 200 md. of grain. Usually wheat is stored in 'teekas'.

In some parts of Doaba in the Punjab 'zamindars' of moderate means store grain in 'pallis' which are very much like 'thekis' and 'pallas' described above. They differ from 'pallas' in being made of gunny cloth and from 'thekis' in having the base made of an iron pan which is tied round the gunny with a rope (Fig. DD).

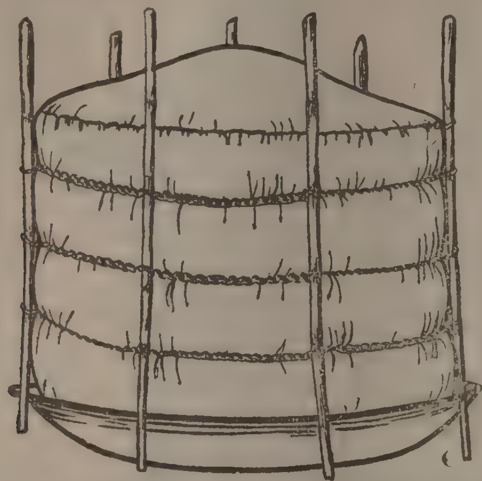
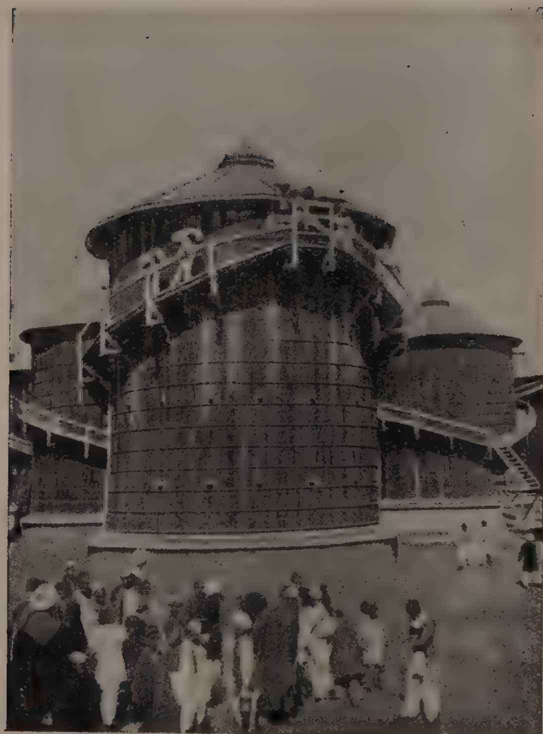


FIG. DD. 'Palla' as used in Doaba (Punjab) for preserving grains

(*f*) Earthen receptacles

Earthen vessels and pots are in universal use for storing small quantities of grain for household purposes (Fig. EE). They vary in size and shape (Plate XI, fig. 2). In some localities especially larger vessels (4 md. capacity) are in use. They are called 'jalas, motkas, mateas, nands' and by various other names in different provinces and States. They are provided with earthen covers or lids and when it is intended to seal them up, the lids are plastered down with a mixture of cowdung and mud.

FIG. EE. Earthenware jars used for preservation of grains



Storing paddy in the State-owned granaries at Srinagar (Kashmir)

(*g*) Metal tins, drums, etc.

Kerosene tins, oil drums, etc. are also used extensively for storing grains on a small scale. They are available everywhere at a small cost and are unbreakable.

Excepting metal receptacles nearly all other structures described above are liable to get damp and are hygienically unclean and therefore stored grain does not remain in a sound and dry condition. Keeping in view the drawbacks of the various kinds of receptacles described above, grains are often stored in bulk in ordinary rooms or special ones set apart for this purpose. In villages some cultivators and 'zamindars' have 'kuchha' rooms, other living with large holdings have 'pucca' cemented rooms. 'kuchha' rooms intended for storage purposes are plastered with a mixture of cowdung and mud. The walls are generally coal-tarred all round, up to where the grain is expected to touch the wall, though this treatment hardly prevents the insects from attacking the grain This type of bulk storage of grain is now becoming prevalent both for storing small and large quantities of grain. In godowns owned by big merchants and commercial chambers, storage is now done in loose heaps instead of gunny bags. Grain is filled in up to the ceiling and wooden planks are used against the door, as the grains are poured in the room. When the room is full up to the height of the door grain is poured through special holes or 'mugs' high up on the wall or in the roof. Ventilators, if present, are used for this purpose. When the grain is required for use, it is taken out by slightly sliding the planks against the main door causing the grain to flow out. In some godowns where there are no doors, bags of grain are used to support the bulk of the grain.

In some parts of the country, small store rooms inside the house are built with solid walls all round and small trap-doors, high up in the wall near the roof. In order to keep the grain as much above the ground as possible, sometimes two storeyed store rooms are built with the room or rooms in the first floor for storage and the space in the ground floor for other purposes. The grain is poured into the room through the trap door. Such houses with wooden walls are found in some parts of the North-West Frontier Province. These houses, built specially for storage purposes, are known by various names such as 'hamras', 'golas', 'kothas', 'kothis', etc.

In Kashmir State special types of wooden granaries, each capable of holding 10,000 maunds of paddy, are in existence. These granaries are directly under the Government management. The granary (Plate XV) looks like a big water tank, encircled by a spiral ramp, raised on 4 ft. high plinth. Paddy is taken up the ramp in bags by coolies and discharged into the granary, and supplies are drawn off from four small trap doors at the base. Internal temperatures are regularly taken and recorded; when the temperature goes beyond 90°F., cool air is forced by means of special blowers.

(*h*) Elevators

Elevators first designed by Robert Dunbar in 1834 are huge buildings having many chambers called 'silos' made of steel, iron, reinforced concrete or brick. In olden days these were built of timber also. These buildings are fitted with the most improved appliances for cleaning and drying grain and transferring the stock to and from wagons, etc. America is the home of elevators.

Elevators are designated according to their ownership and conditions of work as public elevators and private elevators or they may be differentiated purely according to their situation as terminal elevators and country elevators. Terminal elevators are found at large terminal markets and export or import points and country elevators at the smaller country stations along the railway or water transportation lines. The capacity of a terminal elevator is generally 100,000 to 500,000 maunds, while that of a country one is 3,000 to 40,000 maunds. Private elevators may be owned by a company or by an individual, or a group of individuals. Public elevators store grain for any grain dealer or grain firm at a fixed rate depending upon the time of storage, irrespective of ownership.

An elevator installation consists of a group of bins of a suitable size and number served by mechanical appliances. Grain for storage in an elevator is tipped from a cart wagon or a ship into a small pit, called 'boot', having an inclined bottom or duct, as it is called, and from there raised by a

special gear direct to the top of the bin in which the grain is to be stored, or first to a lower elevation, where it enters the cleaning or drying plant if it needs such treatment. From the cleaning and drying plant it passes through an automatic weighing apparatus and thence falls into another ' boot ' ; from this, it is mechanically raised to the top of the bins and discharged upon a system of conveyers so controlled that they deliver the grain into any one of the bins. The base of each bin is sufficiently above ground to provide space for railway wagons or carts. The bins have so-called ' hopper bottoms' through which grain can flow out by gravitation into wagons, bags, or on to another system of conveyers designed to carry the grain in required or stated proportions from several bins and deliver separately or in prescribed mixture into one of the ' boots ' for bagging, loading, cleaning or drying for further storage in another bin. The obvious advantages of elevators from the point of view of insect damage are that 'pucca' bins, in which the grain is stored, are insect-proof. If some store insect, somehow, gains access to the bin, the turning over and cleaning of the grain by mechanical appliances and absence of any cracks and crevices in bins will arrest further progress of insect activity. Lastly, the grain, when it reaches the bin, is absolutely dry and clean and no moisture is absorbed by the grain during storage. For a full account of the construction of different elevators in India and the mechanical appliances therein, the reader is referred to Noel Paton's book on *Indian wheat and grain elevators* (1913). However, there is considerable amount of literature on this subject in other countries, e.g., U. S. A.

The principal advantages of elevator system, however, are—

(i) It expedites and cheapens the handling of grain.

(ii) It secures the grain against damage by rain, etc. and provides a ready means of cleaning and drying.

(iii) It enables the grain-owner to protect himself from heavy loss in the event of fall, in the value of his stock.

In India the use of elevators has not been tested properly.

(ii) Bag storage

Bag storage has certain obvious advantages and disadvantages. Bagged grain is more convenient in handling than grain in bulk but it requires more labour. It permits easy segregation of infested from an uninfested stock. Gunnies easily pick up insect infestation and sometime retain it even inspite of treatment. Because of the inter-bagged air spaces, the temperature and moisture content of grain stored in bags soon comes into equilibrium with that of the atmosphere. Rats have easy access to bags. Both the initial and the recurring cost of bags is heavy.

If weevil infestation starts in a stock of bagged grain, having a moisture content above 14 per cent, the whole stack stands in danger of being ultimately reduced to an unmarketable condition. Even in the drier areas the grains, at any rate those in bags on the outer fringes of a stack, will build-up at times a moisture content which promotes fairly rapid insect development. In the humid regions the build-up is sometimes so high that the grain throughout the stack attains a moisture content, sometimes exceeding 14 per cent, rendering it liable to serious infestation. In these conditions insect multiplication is very rapid particularly when the temperature is favourable. It may be mentioned that an increase of 1 per cent over this figure will result in an enormous increase in the rate of multiplication of store insects. This is specially true when, under the prevalent conditions, it is not possible to have the stores of grain totally free of insect attack. It will be clear that the bagged grain in stacks if once infested and not looked after carefully, may become unfit for human consumption or milling. Keeping in view the disadvantages of bagged storage, the safety of the grain stored for long periods of time in bags will depend upon, (i) the location of stores in places where the climate does not favour rapid insect developments, and (ii) the reduction to a minimum if not complete elimination of the initial infestation.

It is almost impossible to exaggerate the importance of reducing to the minimum the infestation of grain going into a holding store. This requires, (*a*) a clean site, and (*b*) prevention of infested and damp grain from going into the stacks. If a site in which grain had been previously stacked, is to be employed, steps have to be taken to thoroughly disinfest the floor, the walls, the ceiling, the dunnage, and other timbers if lying there. This will involve a considerable amount of time, labour and material and the entire operation would need to be carried out with meticulous care. One of the commonest sources of infestation, as described in the previous chapter, is the godown itself where the left-over grain lies hidden in cracks and crevices and serves as a lodging place for insects. Some insects find themselves absolutely safe behind the loose plaster and the only external indication of such a situation is nothing more than a small hole. As soon as new grain is received in such godowns, the hidden insects, finding conditions suitable, attack the new grain and start breeding. Superficial brooming away of the dust will not achieve the required standard of cleanliness (*see* page 51). Therefore, no store to be used a second time should be recommended unless it is certified to be clean, dry, and uninfested. In most cases in India the buildings are of a variety of shapes and constructional designs and most of them provide ideal conditions for insects to live and breed in. In some cases their locations and constructions are such that to achieve total disinfestation not only is doubtful but impracticable.

Infested bags or damp bags can be prevented from getting into the stores through efficient supervision and inspection. It is of utmost importance that at every store there should be a reliable and trained man for the examination of bags. He should be able to train even the checkers to throw out any bag suspected to be infested or damp, which if not done, would mean inviting serious danger to the rest of the dry and uninfested grain. Once the weevil infestation develops it is not possible to lay the responsibility for weevil development on any one except on those who actually handle the grain.

It is not desirable that bags should touch the walls, and further it is also important, that they should be kept above the floor, because of the danger of the bottom bags picking up moisture from the floor. Even a well constructed cement concrete floor, which appears quite dry, will transmit some moisture to the grain in humid weather ; so proper aeration below the stack is absolutely essential. Therefore, before the grain is received and after the store has been cleaned, it is essential to provide the godown with proper dunnage. Before laying down the dunnage, stack outlines should be marked out according to the space and capacity of the store building. In marking, care should be taken to leave $1\frac{1}{2}$ ft. to 2 ft. space between the walls and stacks and between stacks. About one-fifth of the height should be left clear between the top layer of the bags and the ceilings.

Wooden baulks of 3 in. cross-section and timber battens would make an ideal dunnage to raise the stack off the floor. Failing that, bamboo poles or 'balli' battens may be used. Loose bricks may also be used with advantage. As a last resort, if no other material is available, ordinary matting or 6 in. to 9 in. thick layer of paddy husk may be used, but it must be renewed and cleaned at regular intervals. The practice of placing new matting over the old ones should be avoided as it would give ideal cover under which insect breeding would go on at a rapid rate unnoticed.

On receipt of grain consignments the bags should be carefully examined and any bag which is slack or torn or damp or which shows signs of heavy infestation, should be kept aside. Slack bags should be opened and filled up to standard weight and replaced ; torn bags should be stitched and replaced ; damp bags should be opened and both the grain and the bags be dried in the sun before rebagging. If it is not possible, grain should be consigned for immediate milling.

Heavily infested grain should be stored separately and ear-marked for early disposal. If, however, it has to be held on for some time, it should be cleaned, fumigated, and rebagged. Bags of flour or 'atta', if found damp, should be emptied, dried, and rebagged.

It would be obvious that preventing weevil infestation in bagged grain is a matter :

(i) of enforcing the necessary standards of cleanliness at all stages of grain handling and storing,

(ii) of spotting, rejecting or fumigating infested bags,

(iii) of arranging for the prompt disposal or for immediate milling where signs of weevil development appear in the stock,

(iv) of establishing or holding godowns in suitable localities, and

(v) of organization.

(iii) Effect of air-tight storage on grain and pests

The aims of satisfactory storage are that the grain should remain free from insects and should not deteriorate in quality and lose its germinating power. The question whether the grain will remain in a sound and uninfested condition in air-tight or ventilated storage is controversial. Storing in under-ground pits, which is an ancient practice, involves the principles of air-tight storage. In India it was a common practice to store grain under these conditions in 'khattis' as well as in rooms where reasonable air-tight conditions could be obtained. It is generally believed that under air-tight conditions the grain remains free from insects and, even if they are present, they do not breed and ultimately die. This is apparently due to the accumulation of carbon dioxide in air-spaces between the grains, which is produced as a result of normal respiration of insects and grains. The obvious result is that the presence of carbon dioxide makes the breathing of insects hard so much so that they begin to die of asphyxiation. It may be pointed out that before the insects die the damage done to grain is sometimes considerable, so that in actual practice even if the insects die the grain suffers a good deal of damage.

In 1888, Cotes reviewed the methods of air-tight storage of grain. He asserted that ' ventilation causes the grain to be more weevilled than wheat stacked in bulk or pile which is more air-tight, and ventilation and stirring the grain about appears to develop the pest. The only method to prevent destruction of grain by the weevils is to make the granary air-tight'.

Dendy [1919] concluded that 'within limits of a wide range of conditions as to temperature moisture and degree of weevilling, hermetical sealing is a very effective method of dealing with the weevil problem '. Dendy referred to Professor Zammittis' opinion that ' grain thus stored, can be kept indefinitely, the only evil effect of long storage being an impairment of the germinating power, which becomes torpid and irregular, if grain is stored for more than two years..........' He, therefore, concluded that '.............. hermetical sealing would probably prove to be effective on a large scale, not only as a preventive measure but also as a cure for a badly weevilled grain '.

Brown [1919] reported from Peshawar that grain remained safe if it was kept in airy stores. Fletcher [1923] saw the godowns and while confirming Brown's statement reported : 'The grain was heaped up on the floor of a building of 'deodar'. Grains, stored in mud rooms with the shutters closed and smeared with clay became badly infested with *Trogoderma granaria*. I ascribe the difference to the fact that in the well-ventilated 'deodar' house, the grain is exposed to greater variations of temperature, which prevents heavy infestation'. He added : ' Grain stored in air-tight receptacles (that is to say, as air-tight as is possible in actual practice, by the use of mud sealed bins and so on) is often more heavily attacked, than that left in the open '.

Bhasine [1923] tentatively confirmed the results of Dendy by his laboratory experiments by storing affected wheat in air-tight flasks, etc. But contradictory results were obtained when he tried to have air-tight conditions in receptacles which are used in actual practice for grain storage by Indian cultivators. He said : 'Pitchers were coated with paraffin wax and coal tar and these were the best air-tight conditions we could get, yet after more than a year of storage, living insects were found in the grain. It seems, therefore, that an air-tight condition to ensure total mortality of pests either is not so very easy to obtain or does not work on large scale'.

IV. CONTROL OF STORE PESTS

(i) Hygiene of stores

Storing of grains direct from the threshing yard into a clean godown constitutes a very important preventive measure. It may be emphasized that a threshing yard should be situated about a mile away from the granaries, and should be clean of all faecal matter or rubbish.

Weevils and other store insects live inside cracks and crevices in walls, floor, ceiling, etc., when the stores are empty. They remain actively feeding on the sweepings and any other rubbish which usually remain collected in corners of godowns, below dunnage, or lodged in meshes and seams of bags which unfortunately are usually kept heaped upon stacks, or in a corner of the store. Firstly, such dirty godowns are often not cleaned before new grain is stored and even if they are cleaned, they are only superficially swept off and the rubbish and sweepings are heaped up in a corner of the godown or just pushed off the threshold of the room instead of being destroyed or burnt. *This is a dangerous practice* as it helps to spread store pests to neighbouring granaries where uninfested fresh stocks may be lying. In order that grain should not get contaminated through uncleanliness, it is desirable that before any grain is brought in, the following schedule is fully attended to :

(i) All dirt, rubbish, webbing or refuse material from the store should be swept, removed and incinerated.

(ii) All cracks, crevices, holes in walls, floors or ceiling of the store should be filled in with cement and levelled. All loose plaster on walls should be scraped off and replaced by a new one. All uneven floor or wall surfaces should be brought to level.

(iii) All rat-holes in the godown should be closed by filling them with cement or sand mixed with glass pieces and levelled.

(iv) After the above repairs are carried out and necessary cleanliness achieved, the store should be white-washed if necessary.

If, even after the above operations, the degree of infestation demands the store room to be disinfested, the following methods of disinfestation of godowns, described in order of their importance, are recommended :

(*a*) Thorough and most effective and reliable method of disinfesting any store-room is fumigation. The best fumigant for disinfestation of an empty store is hydrogen cyanide (HCN), if the structural design of the store is satisfactory and expert supervision is available.

(*b*) Benzene hexachloride-(BHC) and dichloro/diphenyl/trichloroethane (DDT) in the form of smoke or dust or as spray with a 50 per cent wettable solution or as 3 per cent kerosene solution will give a satisfactory kill of store pests.

(*c*) Good pyrethrum sprays in white oil (containing ·8 per cent pyrethrin content) at the rate of 6 oz. to 8 oz. per 1,000 c.ft. are known to be effective against store insects.

(*d*) Heat-treatment of empty godowns is also quite satisfactory. But to ensure success it is necessary to provide an elaborate heating system of the entire store building, which is yet not available in India. Burning of charcoal (described hereinafter) in an empty godown is reported to give kill of insects, but the heat thus generated may not reach all crevices in which insects remain lodged. Thus, the full efficacy of charcoal heating is rather doubtful.

(*e*) Burning of sulphur is also sometimes effective.

(*f*) White-washing with lime has also considerable disinfestation value. A few pieces of alum added to the wash will improve its insecticidal effect.

(*g*) Spraying of walls, etc., of the store with kerosene oil emulsion is also useful. The emulsion can be prepared by violently churning oil with two parts of water in which ½ lb.

of soft soap has been dissolved. This treatment may be resorted to in dry areas, where the smell of kerosene oil vanishes more quickly than in humid places, where the smell is likely to persist longer and it is not possible to keep any store unfilled.

(*h*) Well plastered and smooth floors can be washed with any sanitary fluids or water containing 5 per cent solution of carbolic acid or creosote or soft soap.

(*i*) In some parts of India grain merchants give a tar smoke to an empty godown before storage. Others give a smoke of wheat straw or faecal droppings of goats, etc. These are *ad hoc* methods and known to give some relief from insects.

(*j*) Asafœtida dissolved in water is sometimes painted on walls.

(*k*) Painting with coaltar up to about the middle of the height of the walls. This measure has been found in various trade stores and is known to keep off termites.

Before concluding it may be emphasized that in India, it may not be possible to carry out fumigation, the more effective treatment, in most godowns as they are not built for such operations. As such, the choice of any of the above treatments will depend upon the type of constructions, the availability of material and expert advice and the local storage conditions.

(ii) Use of Preservatives

Success in the use of any preservative, organic, inorganic or inert, will depend upon factors such as :

(1) Effect of the preservative on the grain.

(2) The rapidity of its action.

(3) Practicability of mixing the preservative with grain on a large scale.

(4) Possibility of an even admixture.

(5) Period of storage of grain.

(6) Appearance of the treated grain.

When new grain is brought in stores or granaries, it is customary especially with the cultivators to mix the grain with some kind of preservative to keep off pests. The preservatives most commonly used by cultivators and grain merchants and reported to be effective are described below :

(i) In some districts of the Punjab grain is stored in granaries which have been plastered with the juice of a weed called 'marwan'.

(ii) Another general practice in North-West India consists of placing 3 in. to 4 in. thick layers of 'neem' (*Melia azadirachta*) or 'trek' (*Melia azedarach*) leaves in a grain heap. Sometimes the top of the heap is also covered with these leaves. Such regular layers are generally possible in receptacles such as, 'thekas'. Haphazard mixing of the leaves is also a usual practice. In certain places leaves of 'senji' (*Melilotous parviflora*) are also used, but they are known to be less useful.

(iii) In certain parts of India, pulses and other grains are said to remain free from insect attack if some quantity of 'murhi' (fried rice), is also spread on the top of the grain. In some hilly parts of the North-West Frontier Province, burnt salt is mixed with stored rice and paddy.

(iv) Preservatives in the form of dusts have been in use for a long time in India for protection against store insects.

According to the mode of action dusts are classed as (*a*) chemical or poisonous, (*b*) mineral or inert dusts. Chemical dusts bring about the death of store insects by chemical action, while mineral or inert dusts are believed to kill through desiccation, etc., and are not poisonous to man and livestock. The various common dusts are described below under these two categories :

(a) Poisonous or chemical dusts

Poisonous dusts, as a rule, should be used only in the case of grain meant for seed purposes. However, some of the dusts described below can be used in carefully determined dosages at which they prove harmless to humans. In any case full toxicity data or physiological effects of such dusts should be studied before their use in grain meant for human consumption is recommended. Simple and obvious kill of insects should not lead to the use of such dusts indiscriminately.

Copper carbonate. This chemical applied at the rate of 2 oz. per maund gives a complete kill of pests like *Tribolium* spp. *Oryzaephilus surinamensis*, etc. Insects become sluggish, and inactive under the effect of this dust. Their feeding and reproductive activities cease until they die in about a week's time.

Copper carbonate used at the rate of 1 to 200 parts by weight of grain does not affect the germinating capacity of grain. Unfortunately it cannot be used to protect grain meant for human consumption as there is likelihood of copper poisoning.

Sodium, calcium or barium fluosilicates and sodium fluoride. In several parts of the world these chemicals have been tried against insect pests of stored maize, especially *Sitophilus oryza*, at the rate of ½oz. to about 60 lb. of grain, securing complete kill and perfect protection in about a week's time. *Tribolium castaneum* is known to be more resistant to sodium fluosilicate but like *Sitophilus/oryza* it is killed by sodium fluoride. Barium fluosilicate is used at the rate of 1 : 1,500 by weight.

At New Delhi, we have found in the case of 'jowar' seed that sodium fluoride is more effective than sodium fluosilicate although the dose may be 1 : 2,500 and 1 : 1,500 respectively.

Borax. It is used for protecting grains stored for seed purposes only. It is mixed at the rate of 1 oz. in about a maund of grain. This dose is effective against *S. oryza*, *Sitotroga cerealella* for at least seven months. *Bruchus* spp. are known to be killed by the application of very high dosages of borax [Schwardt, 1930] which are obviously not economical.

Calcium chloride. It is an effective dust against Bruchids. Tests carried out with this chemical at the rate of 1 : 40 by weight afforded complete protection to 'jowar' grain against store insects. Its extreme adhesive nature accounts for its effectiveness, but being a dehydrating agent, it impairs to a considerable extent the germinating power of treated grain.

Pyrethrum. Pyrethrum extracts are often mixed with various inert substances such as talc, chalk, etc. Pyrethrum dust thoroughly mixed with grain at the rate of 1 lb. in about 240 maunds is reported to give satisfactory kill and the treated grain can be safely used as food for animals Farrar, 1939]. The dust should be prepared just before application as it rapidly deteriorates.

Dutox, Dawson and Anderson clays. These clays are commonly used in the United States and are known to act as repellent, especially against Bruchids. Dutox clay contains 80 per cent barium fluosilicate. It is known to be effective at the rate of 1 : 4 by weight. Their effectiveness depends on the degree of their adhesiveness to the grain. None of these dusts is known to affect the germinating capacity of grain or impair its food value or the cooking quality. Anderson clay is reported to give satisfactory results at the rate of 1 : 75 by weight [Marcovitch, 1937].

Mercury. In 1906, Krogh found mercury to be toxic to the larvæ and eggs of some insects That mercury vapours are highly toxic to insect eggs was known even much earlier in Denmark. Kannan [1919] found in Mysore that eggs of store insects are affected by mercury vapours. He developed the idea from the age-long practice among cultivators of Mysore and North Gujerat of using mercury as a protection against pulses getting infested. The practice consisted of placing a drop of mercury in an excavated soap nut and burying it in stored pulses. This was corroborated in the U.S.A. against *Bruchus quadrimaculatus* and it was pointed out that mercury could be used with a very negligible loss several times over.

Horsefall [1928] used mercury in the form of dusts : Dip-dust (4 per cent nitrophenol mercury) and Bayer's dust (2 per cent nitrophenol mercury). Dip-dust was used against Bruchids and the other against *Sitotroga cerealella* and both were found effective at the rate of 1 : 384 by weight.

Dutt and Puri [1929] made trials at Pusa in which mercury was placed in more porous containers to allow its vapours to pass out much more easily. These containers proved to be very effective. In order to avoid leakage of mercury at the time of examining the grain and its droplets getting mixed with the grain, various amalgams of mercury were tried and tin-mercury amalgam (2 : 3) was found to be the most suitable and convenient for use . One ounce of amalgam was found enough for one maund without affecting the germinating power of the grain and the health of the consumer.

In the North-West Frontier Province, about 1 oz. of mercury mixed in one seer of *Carum copticum* 'ajwain' and four seers of cowdung ashes are first mixed together and then with the grain. A part of the mixture is spread on the floor before the grain is put on it. The thin layer of mixture is again spread on the top of the pile. This practice, though reported to give sufficient protection against insect attack, is not safe in so far as it allows mixing of free mercury with the grain.

Cartwright [1930] also observed that dust containing mercury was effective against pests of stored pulses. Christensen, Krogh and Nielsen [1937] also referred to the toxic effect of mercury vapour in closed chamber.

Gough [1938] gave a review of the entire work of Bovingdon who considered it wise not to use free mercury in experimental work against store insects.

In 1944, Wright found that mercury vapours are effective against the eggs of *Calandra*, *Rhizopertha* and *Sitotroga*. Zinc and tin amalgams and calomel were more effective than pure metallic mercury. He further concluded that the efficacy of a given weight of mercury is increased by sub division ; that mercury in a finally divided form incorporated in a solid base is more toxic and that storage in mercury vapours has no effect on the viability of adult weevils, nor does it affect their subsequent reproductive capacity, while eggs are very susceptible to mercury vapour.

Dole [1943] studied the effect of a coating of mercury (dispersion in calcium carbonate) on porous strips of paper with a view to measuring their efficacy in preserving stored grains from insect attack. Keeping of such strips in grain was found to be very effective. By this method it is possible to preserve grain by the application of mercury at the rate of 8 gm. per ton of grain stored in a space of 1800 c.ft. under suitable conditions. This method has been tried in India and it is found that in this method also there is a danger of free mercury getting mixed with grain and proving a slow poison to consumers.

Krishnamurthi and Appanna's [1945] results of their experiments with mercury against *Corcyra*, *Bruchus*, *Tribolium* and *Rhizopertha* are summarized below :

(i) 0·03 gm. of mercury is completely effective against eggs in a space of 3,300 c.c.

(ii) *Corcyra* eggs of more than 24 to 48 hours of age are not affected by mercury vapour.

(iii) The vapour enters the eggs through the micropyle.

(iv) The minimum period required for volatilization of the lethal dose is 48 hours.

Richards [1945] tried the effect of mercury vapour on the eggs of *Sitophilus granaria*. He found mercury vapour very toxic at low temperatures, penetrating to a considerable depth of grain. No development of eggs takes place while they are exposed to the vapour but a certain amount, depending on the length of exposure, may take place afterwards. He further concluded that pretreatment of grain with mercury vapour makes no difference in the fertility of eggs afterwards laid in it.

To conclude, mercury vapour in very small doses has considerable ovicidal value but there is yet no unanimity as to how it should be used to avoid risk to consumers.

The use of DDT and benzene hexachloride is described under insecticides in the section on Remedial measures.

(b) *Inert dusts*

It is well known that some insects can be killed by finely powdered materials or dusts, which are not poisonous in the common sense of the word. Farmers in all countries have been employing even road dust, ashes, etc. as a protective covering for the grain. It is a common practice in India to cover a heap of grain with a layer of sand, ashes or road dust.

Tests carried out by us at New Delhi with a large number of inert dusts indicated calcium carbonate to be the most effective, while lime and sulphur giving less promising results. Tests with indigenous rock-phosphates found in large quantities in India also gave good results.

During World War II, considerable amount of work on inert dusts was done in the United Kingdom, Australia, etc. Briscoe and his colleagues [1943] tested many dusts and found finely ground diamond carborundum and particularly the common coal ash clinker to be the best available one. It is a hard substance and its silica content is firmly bound as silicates of iron and calcium, eliminating the risk of silicosis. Parkin [1944] after testing about 28 dusts from blast furnaces, clinker power stations, found finely powdered flint to be the most effective and felspar and dolomite very promising. Claus [1939], Ratcliff *et al* [1940] and Cotton *et al* [1942] considered that in practice the mineral dusts are not likely to prove effective and convenient to use as might be expected. Though most of the dusts can be cleaned and removed from the surface of the grain during milling processes, it is difficult to remove dust which goes inside the infested and damaged grain. It is, therefore, necessary that the grain to be treated with dust should be sound and undamaged. There is another important reason why only sound grain should be treated with dusts. Larvæ of insects such as *Sitophilus*, *Sitotroga* and Bruchids spend their larval period inside the grain. No amount of outer covering of dusts will kill them.

The manner in which inert dusts kill insects is not precisely known, but it is certain that they cause a good deal of loss of water from the tissues, though the mechanism of this loss has yet to be explained. The investigations carried out by various workers during the past two decades or so show that the effect of dusts is due to a combination of factors such as mechanical action, starvation and desiccation. Desiccation theory originally propounded by Zacher and Kunike [1930] and later developed by Germar [1936] seems to hold the ground. Mechanical factors seem also to be of some importance. However, the following facts stand out prominently when the data obtained by Zacher [1930], Germar [1936], Chiu [1939], Briscoe [1943], Parkin [1944] and other workers are carefully studied :

(i) There is a definite relation between efficacy and particle size of dust. Finer the particle the higher the insecticidal efficacy. The particle size at which the dust can be most effective lies below five microns, but most of the dusts show their efficacy up to 10 microns particle size. Coarser particles do not stick to the insect or the grain. Certain dusts are, however, completely ineffective even when finely ground.

(ii) As a general rule, the effectiveness of dusts increases with the intrinsic hardness of their particles. For example, hard substances like diamond, carborundum and flint give better results than soft substances like calcites,china clay, etc. Generally, hard materials with G. 5 on Moh's scale have proved effective. On the other hand a few comparatively soft materials, e.g. zinc blende, magnesite, glena are very effective, while some hard substances like artificial titanium oxide are comparatively ineffective. Investigations indicate that there is no relation between the hardness of insect cuticle and that of effective dust particles. As such it is not hardness but some other factor correlated with hardness which is effective.

(iii) The shape and form of the particle is also important. As a rule, hard crystalline and angular substances have proved effective. However, amorphous subseadces, e.g. flint, colloidal silica, etc. are also said to be effective.

(iv) Humidity has a very pronounced effect on the insecticidal action of inert dusts. At 75 per cent relative humidity, the effect of a dust is slowed down and at relative humidity of 90 per cent the dusts become completely ineffective. In coastal areas or those having high rainfalls, therefore, inert dusts cannot be used with advantage.

A large number of inert or mineral dusts have been in use for a long time in different parts of the world. Of these, some are marketed under commercial names, such as 'katelsousse' in Egypt, 'naaki' in Germany, 'vivianite' in Russia, '*neosyl*' and '*fygran*' in the United Kingdom. A brief account of various dusts known to be effective is given below :

(i) *Wood ashes or coal ashes.* Use of ashes is an ancient practice in India. They are effective when used in the ratio of about 1 : 4 by weight. Sometimes the use of ashes at the rate of even 1 : 2 by weight has been found effective without affecting the germinating power of the grain.

(ii) *Lime.* Burnt lime, hydrated lime of calcium hydroxide and calcium carbonate have been found effective when used in the ratio of 1 : 2. This practice does not impair the germinating power of the grain but it prevents the larvae from further normal development. Japanese trade has always considered rice treated with calcium carbonate superior in flavour to the untreated one. This practice originated through the use of calcium carbonate in milling to prevent the development of 'heat' by friction which results in the loss of flavour. This custom is said to be so common that the very slight flavour which is given by calcium is considered desirable.

(iii) *Gypsum* (*calcium sulphate*), *calcium chloride*, *etc.* Commercial gypsum which contains calcium oxide 46·8 per cent and sulphate radical 62·6 per cent has been found by various workers to be effective, particularly, against Bruchids. The dosage recommended is 1 : 64 by weight. Because of the adhesiveness, this dust prevents Bruchids from obtaining a hold on the surface of the grain to drill their way in. Calcium chloride like calcium sulphate is effective also due to its adhesive nature. Its dose is the same.

(iv) *Magnesite* (*magnesium carbonate*). The Australian Council for Industrial and Scientific Research in their 13th Annual Report for 1940-41 recommended the use of this dust on a large scale. Its effective dose is about 2 per cent by weight. Its insecticidal properties are reported to increase by adding small concentrations of DDT(1 : 1,000) and benzene hexachloride (1 : 10,000).

(v) *Magnesium oxide and hydroxide.* The magnesium hydroxide dust is more effective than magnesium oxide and is used at the rate of 0·4 per cent by weight. Micronized magnesium oxide being non-toxic can be dusted freely on walls, ceilings of stores as well as on bags of grain. One pound of magnesium oxide is reported to be enough to treat 6,000 c. ft. of empty space.

(vi) *Silica and its compounds.* Finely powdered silicic acid is reported to afford satisfactory protection to maize against store insects. Particles of these dusts are reported to enter the joints of insects, accumulate there and thus hinder the movement of the mouth parts which eventually results in their starvation and death.

Silica mixed with magnesium oxide at the rate of two to three per cent or above, is reported to give useful results. The Department of Scientific and Industrial Research, London, found the crystalline form (compound of silica 98 per cent and water 2 per cent with small quantities of aluminium, iron, calcium and magnesium salts) to be effective. The particles were below 10 micron in size. Dust, containing free silica, should not be used on account of the risk of the workers developing silicosis.

'Naaki' is a famous dust used in Germany. It is the pure quartz sand ground to different grades of fineness It mostly consists of silicic acid (90 per cent) with a small amount of iron, lime, aluminium and magnesium salts. Effective dose against *Sitophilus* spp., *Oryzæphilus surinamensis*, and *Bruchus* spp. is 1 per cent by weight.

Talc is the hydrous silicate of magnesia, well-known as soap-stone. It is used at the rate of 1 : 60 by weight to afford effective protection to grain against store insects.

The famous clay ' bentonite ' is volcanic in origin, consisting chiefly of hydrous silicate of aluminium. This and China clay afford protection to grain. Diatomaceous earth containing siliceous cell-walls of fossil diatoms-calcined and ground with 90 per cent of particles of size below 10 microns—has also been found effective.

'Activated prophyllite' or hydrous aluminium silicate is known to be effective at the rate of 1 : 3 by weight.

(vii) *Phosphates.* Rock phosphates are well-known for preserving grains against pest attack. The famous ' katelsousse ' of Egypt is a finely ground mixture of over 83 per cent calcium phosphate and 15 to 17 per cent sulphur. It is used throughout the Middle East on a very large scale. It is mixed with grain stored in bulk in the open.

The famous ' vivianite ' is a hydrated ferrous phosphate dust most widely used in Russia. Its general dose is 0·5 per cent to two per cent and in stocks infested with mites, 1 to 100 parts is enough.

(iii) Screening of grain

Among the various methods of insect control, the destruction by mechanical methods is some times the most practical. This method may arbitrarily be distinguished from other methods in that they involve the use of special equipment with immediate and tangible results. On this account they are psychologically good and generally popular, though they may be comparatively slightly costly in time and labour. Among these mechanical methods used against insect pests of stored grain, with which we are concerned, screening of grain is very outstanding, the importance of which, unfortunately, is very seldom realized, both in its effect on insect population and its economic value.

Screening is more effective and practical than it is generally believed to be. Screening can easily be adjusted in the ordinary routine of godown management. The obvious result of screening is that it takes away a large amount of the insect population from the infested grain and gives the grain a sound, attractive and healthy appearance to be passed on as a ' fair average quality ' although it is not totally insect-free. Unscreened grain always stands chances of being rejected straightway, which means a loss of foodgrain, prestige and goodwill in the commercial field.

Another important feature of screening is that while grain is being sent from the docks, railway sidings, etc. to the holding godowns, screening positively aids in reducing the chances of dissemination of insect and spread of infestation of insect pests throughout the areas through which the grain passes (which otherwise would have been many) and keeps the rolling stock free from insect infestation. The importance of the elimination of obvious and open contamination is very seldom realized in its real perspective by those who are responsible for grain handling, specially the infested grain.

Screening machines are quite simple in structure and easy to operate. They vary in their designs but generally two sieves, each fitted on a frame, are fixed one upon the other. One of the sieves, generally the upper one, has large meshes and therefore retains only large foreign matters. The lower one is with small mesh and is generally used to screen up the smaller matters. It is always better to use the type which has an exit hole beneath the upper end of the upper sieve to which a bag or any container can be fitted to receive the screenings including dust, etc. The obvious advantage would be to prevent the screenings being blown about and thereby causing an all round dissemination of insect infestation. The machine should be adjusted at an angle to ensure that the flow of the grain over the sieve is neither too quick nor too slow.

The following points should always be observed when carrying out screening :

(i) Screening should be a regular practice and the grain should not be allowed to pass unscreened on the mere ground that it was not considered sufficiently infested. Every insect destroyed means saving grain from subsequent insect depredation. In this case, it may be recalled that one pair of insects can produce several thousands in a couple of months when plenty of food is available.

(ii) Screening sites should always be arranged as far away from the main stores as possible. But if due to certain local conditions the screening has to be done near about the stores the doors and windows must be kept properly closed during the screening operation.

(iii) The screening operations should be carried as far apart as the space permits. The main idea is to avoid congestion. The insects may fly about and reinfest the cleaned grain.

(iv) Screenings should on no account be allowed to remain heaped in or outside the stores. They should be promptly incinerated. It has been noticed that sometimes for want of one thing or another, the screenings are not immediately destroyed. This means exposing the grain to contamination and thus defeating the very purpose for which screening was carried out. Destruction of screenings will be a gain and not a loss so far as it eliminates chances of insect infestation and dissemination. It is, therefore, advisable to plan ahead for the prompt disposal of the screening. It is generally believed that incineration is not practicable. But this has been and is being done successfully at several places.

(v) The bags used to carry screenings to the place of disposal should never be used for sound and clean grain. If circumstances compel their use, they should be thoroughly disinfested by heat-treatment or by fumigation if facilities for such a treatment are available in the locality. In the absence of any of the above facilities, heat may be taken by exposing the infested bags in the open to the sun and brushing off the insects that may be lodging in the seams or in meshes. This will not completely disinfest bags but this *ad hoc* treatment would be better than no treatment. Bags cleaned this way should be used only in exceptional emergencies.

(iv) Remedial measures

It would be clear from the account of the habits and biology of store pests described in previous pages that damage by insects is either obvious in the very beginning as in the case of *Tribolium castaneum* whose larvae are freely living among the food particles or grains or it is evident only when they reach the adult stage as in *Sitophilus oryza*, *Rhizopertha*, etc. In the latter case the damage is not distinctly noticeable till the larvae, developing within the grain, mature and eat their way out. In the latter case the use of preservative dusts, as already stated, may prove of little value. Moreover, in actual practice very few stores remain eventually free from pests. In such cases, it is incumbent to adopt such measures which can bring about a complete control of pests. Moreover, in cases of heavy infestations it is not possible to achieve satisfactory results with preservatives, especially because it is very difficult to mix them properly with huge stocks of grain. It is, therefore, often necessary to resort to remedial measures.

The eradication of store pests from infested stocks can be effected by the use of a stomach or contact poison or by fumigation with a poisonous gas. Stomach poisons cannot be used in the case of grain or grain product intended for human consumption. Contact poisons will rather spoil the grain than, kill the pests, the majority of which are hard-bodied beetles and weevils. Therefore, fumigation is the only effective method so far as poisons go for the eradication of store pests. It has already been emphasized that excessive heat plays an important part in keeping down the population of pests. In fact most store pests die if exposed to a temperature of 120°F. for half an hour or so. Thus ' heat treatment ' is also adopted as a practical measure for disinfecting stored products.

Fumigation

Insecticides used in the gaseous form for killing insects are called fumigants and fumigation is the process of exposing insects or any material infested with insects to the fumes of any chemical at a lethal strength in an enclosed space. The fumes of burning sulphur have been utilized for the disinfestation of residential buildings and with several other herbs, etc. for over thousands of years.

Considerable development of fumigants for insecticidal purposes has taken place during the past 50 years or so although several types of fumigants such as carbon bisulphide were discovered about a century ago. The problem of fumigation resolves itself into two categories :

(i) Scientific principles governing the successful use of fumigants under practical storage conditions ; and

(ii) Suitability of a particular fumigant for different types of stored grain and its products, insect pests of which can be killed by such a fumigant.

The exact mode of action of fumigants on various insects is a highly technical problem and its discussion is beyond the scope of the present work. In general it is quite enough to say that fumigants reach the tissues of the vital points of insects through the spiracles and they kill insects by preventing in one way or the other the absorption of oxygen by their tissues. Simple asphyxiants such as nitrogen or hydrogen undoubtedly cause death by mechanically preventing oxygen from reaching the insect. These are not so effective as other fumigants since most of the insects cannot be killed by merely being deprived of oxygen because they often revive after some time. Typical fumigants apparently exert a disastrous effect upon the activities of certain enzymes associated with the cell respiration preventing the tissues from coming into contact with oxygen in a normal manner.

The success of a fumigant in killing insects depends upon, (*a*) concentration of the gaseous vapours per cubic foot of space to be fumigated, and (*b*) length of time for which pests remain exposed to the fumigant at a lethal concentration.

Most of the fumigants are supplied in liquid form and in the process of vaporizing they absorb heat. The heat may be taken from air, from the building itself or the material to be fumigated or the liquid fumigant itself. In a country like India where the temperature in most of the places is fairly high for a long period, the vaporization would be fairly rapid. In cold weather, however, it may be necessary to apply artificial heat to bring about quick vaporization.

After a fumigant has been introduced into an enclosed space and vaporized, the next step is its uniform distribution throughout the treated space. Given sufficient time, and no interference by other factors, diffusion of gas with the atmosphere of the enclosed space will be complete and uniform, for it is necessary that the gas and the air should mix as evenly as possible. Quick and proper diffusion can be relied on in small spaces but in large godowns it may be necessary to ensure rapid mixing by means of electric fans, etc. This is true mostly of gases heavier than air.

Penetration of a gas mainly depends on the rate of diffusion. In the case of bags of grain, the stacks should be so arranged that the maximum surface is exposed. Some believe that in large bulks of grain, it is not possible for gases to penetrate because of the air spaces being largely reduced due to the pressure of grains on the spaces. But in effect the amount of air space in the case of whole grain is about 40 per cent and about 60 per cent in the case of milled products. Not only will the intergranular air be replaced by the fumigant but even the grain will get coated by the gas.

The diffusion and proper penetration of gases is counteracted by the absorptive capacity of the material. It is, therefore, essential that absorptive capacity of the material to be fumigated is known or determined before starting fumigation. Wheat flour has, for example, higher absorptive capacity than wheat grain.

Density of the fumigant greatly influences the distribution of the gas. The heavier the fumigant the longer it may remain in low spots along floors or basements, etc. unless the air and the fumigant are artificially stirred. For instance, carbon bisulphide or ethylene dichloride shall have to be discharged in the upper region of a room or at the top of the material to be fumigated, while a fumigant like hydrogen cyanide which is lighter than air is often applied at the bottom.

As mentioned above, temperature is an important factor in determining the effectiveness of a fumigant. Volatility increases whereas surface absorption decreases with rising temperature.

Moreover, rise in temperature affects the physiological activity of the insects which are cold-blooded animals. It, therefore, follows that fumigation at 80°F. will be more rapidly effective than at 60°F.

While for some insects a change of humidity within limits does not greatly affect their resistance to fumigation, a change of relative humidity and moisture content of their food may be important. Hydrogen cyanide and sulphur dioxide are highly absorbed by cereals having high moisture content. It is, therefore, necessary that for hydrogen cyanide fumigation, the moisture content of the grain is less than 10 per cent. On the other hand, some fumigants which are solvents for fats or oils will not be absorbed by ordinary cereals.

Some of the absorbed fumigant is given off during airing, but a small proportion may be retained for long periods. Residual traces of the fumigants in ordinary use have, as far as known, no adverse effect on the nutritive value of food. Some of the fumigants such as hydrogen cyanide, ethyl or methyl formates may even occur in traces in certain foods. The choice of the fumigant and the intensity of treatment should be carefully determined to ensure that there is minimum amount of residue and the least possible risk of damage to the nutritive value of food.

Since most of the fumigants are more or less toxic to man if inhaled and others toxic if digested, it is necessary that proper aeration of the fumigated buildings is effected before human beings enter them. Generally the concentration of the gas in the air falls to a safe limit within a few hours but airing of the building must be continued much longer in order to remove the fumigant from the grain and walls of the buildings, etc. The period generally required depends mainly on the absorptive power of the material and on the volume of the less accessible spaces. Doors, windows and ventilators should be opened to effect proper and thorough aeration. On still days it may be necessary to employ blowers.

No hard and fast rules of dosage in the case of various fumigants can be defined but the dosage tried under optimum conditions of temperature and humidity have been given under each fumigant. A particular insect may be relatively resistant to some fumigants and susceptible to others. Similarly, different stages of insects vary in their susceptibility which is mostly dependent on the rate of their respiration. In general the dosage will depend upon :

(*a*) The nature of the material to be fumigated.

(*b*) The insect and the stage of its growth infesting the material.

(*c*) Air-tightness of the building.

(*d*) Nature and arrangement of the bags or other food packages.

(*e*) The prevailing temperature. It should not be less than 65° F.

(*f*) Moisture content of the grain, which should be less than 10 per cent.

A single fumigation, however effective it may be, does not by itself give a complete control over long periods. It is, therefore, necessary to repeat the treatment at suitable intervals which can be determined by periodic examination. Reinfestation by crawling, migrating or flying insects is almost certain under actual storage conditions.

Ordinary buildings are seldom satisfactory for fumigation operations owing to the loss of fumigants by absorption by the building material and by leakage. The rate of leakage will vary with the type of construction and the wind velocity, and the efficiency of ceiling. It is, therefore, desirable to have special fumigation chambers constructed of cement concrete, or brick with walls well-plastered and floor of dense concrete and covered with a bituminous compound. The surface should be coated with cellulose paint or any such material which does not absorb the gases. The chamber should be fitted with a wide door on one side and a window opposite, both opening to the outside. The ventilator should be fitted with a fan to facilitate airing. The door and window should have the necessary fittings to make them gas-tight when closed. The capacity of the chamber would depend on the actual needs.

As pointed out above, all fumigants are more or less toxic to human beings and domestic animals. Care should, therefore, be taken to avoid exposure of workers to the vapours of fumigants. The following precautions should be taken while using fumigants :

(i) When buying a fumigant appropriate literature on the fumigant should be obtained and studied.

(ii) The fumigant should be stored in a cool, dry, well-ventilated and a safe place under lock and key.

(iii) Fumigation should be carried out by a trained operator and an assistant who understands the operation. They should be properly equipped with gas-masks during the course of fumigation operation.

(iv) First-aid equipment should be ready at hand during fumigation.

(v) When sealing a building, it should be ensured that doors and windows open from outside. Otherwise arrangements should be made to that effect.

(vi) Before starting fumigation it should be ensured that the building is empty of human beings and domestic animals.

(vii) Hands should be thoroughly washed after the operation.

(viii) The building during the process of fumigation should be locked putting a warning sign at the entrance of the building such as '*POISON GAS—DANGER*' till it has been thoroughly ventilated and entry of human beings is declared safe.

The most common fumigants are described below :

Hydrogen cyanide (*HCN*). This is one of the most widely used fumigants in the world. It is highly poisonous and therefore needs expert handling. In some countries the use of this fumigant is subject to strict regulations. For instance, in the United Kingdom this fumigation can be undertaken only by those who have at least 18 months' continual experience. In Germany, the regulations are even more strict. The fumigator may lose his license if there is a break even for a short period in his fumigation experience.

Hydrogen cyanide is a colourless, highly volatile liquid with a specific gravity of 0·697 at about 65°F. It weighs 6 pounds to a gallon. In physical properties it is much like water but boils at 78·8°F. Under Indian conditions it will evaporate very rapidly into a gas which is slightly lighter than air and extremely poisonous to any form of life. One pound of the gas occupies approximately 14 c.ft. at atmospheric pressure. It diffuses very quickly, being lighter than air and the diffusion is mainly directed upwards and outwards. Under normal atmospheric pressure, the gas does not readily penetrate closely packed materials such as stacks of bags of grain or flour, or rolls of bags, etc. This is generally overcome by employing the gas under partial vacuum. The gas is not dangerously inflammable at ordinary temperatures unless used at about four pounds per 1,000 c.ft. or at volume concentration of about 5·6 per cent. To ensure complete safety it is desirable not to have any fire in or near the building to be fumigated. It has a smell resembling that of bitter almonds, and is readily soluble in water. It superficially tarnishes metals which can be cleaned by simply rubbing or polishing. It does not affect any colouring of fabrics or papers.

Hydrogen cyanide is produced from cyanides of alkali metals such as sodium, calcium and potassium cyanides. Calcium cyanide is an unstable salt readily yielding gas. But other salts need treatment with acids such as sulphuric acid to liberate the gas. There are three principal methods for the use of hydrogen cyanide .

(*a*) The oldest method of generating the gas is what is described as the 'pot metџod'. The gas is produced by mixing sodium cyanide (97 to 98 per cent purity) or potassium cyanide with dilute commercial sulphuric acid. Commercially concentrated sulphuric acid (specific gravity 1·83,

will be satisfactory for the purpose. The various ingredients should be used in the following pro portions for every 100 c.ft. of empty space in the order given :

Water	2 fluid oz.
Commercial sulphuric acid (1·83 specific gravity) .	$1\frac{1}{2}$ fluid oz. ($2\frac{3}{4}$ oz. by weight).
Sodium cyanide or potassium cyanide* . . .	1 oz. by weight.

Vessels for generating hydrocyanic acid gas should be of acid-and heat-resisting material. Earthe ware jars, glass-basins, glazed china-ware pots prove satisfactory for the purpose. Capacit of the pot should be nearly two and a half pounds for every 2 oz. of the cyanide compound to b used, to avoid the overflow of the liquid on the floor. In any case the contents should not com within four inches of the rim of the pot.

The pot or pots should then be placed on the floor in the room to be fumigated. The vessel ma be placed on a bed of sand to protect the floor against any drop of acid falling on the ground. Measure quantity of the water should be poured in the pot. Then the measured quantity of the acid is poure slowly keeping the liquid stirred with a glass stirrer to avoid bubbling and consequent splashin of the acid on the operator's face.

Before the chemicals are mixed, the operator should make sure that all water, moist food or an other materials are removed from the room under fumigation, because otherwise hydrogen cyanid being soluble in water, the moist materials and foodstuffs would absorb the gas and become poisoned All doors, windows and ventilators should be closed air-tight, excepting one door by which the operato has to go in and come out. Any points of leakage should be covered with gummed tapes or paper pasted against the surface. It should be ensured that doors, windows and ventilators open to th outside, if not, arrangements should be made to bring about this change. The liquid mixtur should be allowed to stand a while and get cooled. In a large room more than one container may b used and these may be placed at regular distances, in one or two rows, in order to obtain even distri bution of the gas.

Finally, a last look-round should be given to make sure of the above and that no unauthorize person or animal is present in the room and that the operator is fully equipped with gas masks. Cyanid should be wrapped in thick paper to avoid violent action of the chemicals and carefully slid or lowere into the dilute sulphuric acid. The chemicals react on contact and the gas is generated almost ins tantaneously. The room should, therefore, be always vacated through the open door immediatel after lowering the cyanide into the acid. If more than one vessels are used, it is desirable to hav also more than one operator. The room should be atonce sealed, locked and plackarded—'POISON GAS—DANGER'—to prevent mistaken entry of any one.

After 24 to 36 hours, the doors, ventilators and windows should be opened out with the help of a long wooden pole, the operator standing at some distance if no other arrangement exists. The room should be allowed to have a free circulation of fresh air for at least six to eight hours. On a still or humid day ventilation for several hours may be necessary. Artificial stirring by means of fans may be adopted to obtain quick removal of the gas.

When the building has been thoroughly ventilated and certified that it is free from cyanide, the residue in the vessels must be removed very carefully or buried and the vessel thoroughly washed. While doing so, it is necessary to breathe as little as possible and the operator should not hold his head directly over the barrel, as on shaking the vessel some more gas may be generated. Whether any trace of HCN is present in a store or any enclosed space after ventilation can be detected by the use of methyl orange test papers available in small strips. In the presence of HCN orange colour of the paper immediately turns pink or red. If there is no change in the colour within about 2-3 minutes after exposure the space should be safe for entry.

* Potassium cyanide comparatively gives out about 25 per cent less of hydrocyanic acid gas

Hydrogen cyanide is also produced by the use of automatic generators with capacities of about 10 lb. to 25 lb. Sodium cyanide and dilute sulphuric acid are introduced into the generators which automatically generate and discharge hydrocyanic acid gas. In many countries this method is used instead of the 'pot method' to obviate risks, especially where large amounts of the gas are needed.

(*b*) Hydrocyanic acid gas can also be produced by the use of calcium cyanide. This is the simplest method of generating the gas and is in common use since 1916. When calcium cyanide is exposed to the atmosphere, it absorbs moisture from the air, which initiates a chemical action by which hydrocyanic acid gas is given off. Calcium cyanide is available in the following forms:

(i) Calcid is a German product available in the form of bricks in sealed tins. It contains about 50 per cent hydrogen cyanide by weight.

(ii) Cyanogas is an American product available in powdered (Cyanogas A) or granular form (Cyanogas G) in sealed tins. It has about 25 per cent hydrogen cyanide contents by weight.

(iii) Cymag is a British product and like cyanogas in form and contains only 20 per cent hydrogen cyanide.

The method of application of calcium cyanide is very simple. The required number of tins should be distributed over the building. It is better if sheets of paper are laid over the floor over which the powder is thinly scattered. The scattering should be done farthest from the exit in order to keep away from the gas which is given off. The floors should not be wet in any case.

The usual dose is 1½ oz. of Cyanogas per 1,000 c. ft. of empty space. On this basis, the dosage for other forms can be calculated. The form containing about 25 per cent of available hydrogen cyanide is used to some extent for the fumigation of grain. The fumigant is usually fed into the stream of grain as the bin is filled. Calcium cyanide is also introduced into a store containing bags of grain by means of specially constructed gunniting machines. This is reported to have given very satisfactory results in disinfesting grain in Madras. About 10 ℔. of the chemical per 1,000 maunds of grain gives satisfactory results.

Calcium cyanide does not have any deleterious effect upon the treated grain. Its milling and baking qualities, and germinating powers remain unaffected. However, white corn or polished rice should not be treated with any form of calcium cyanide since the white grains get tainted or covered with yellow spots. The freshly harvested grain of any commodity is also liable to be damaged by fumigation with calcium cyanide because of its moisture content.

(*c*) Hydrocyanic acid gas can be produced by the vaporization of liquid hydrogen cyanide. This method is more extensively used in America for the disinfestation of mill premises. Liquid hydrogen cyanide (96 to 98 per cent pure HCN content) is available in steel cylinders of 30 lb. to 75 lb. capacity. The gas is stored under pressure in cylinders and is delivered through pipes fitted with atomizers into an enclosed space that needs fumigation. The liquid almost immediately produces the gas where the use of liquid HCN is not practicable, use of discs is recommended. Liquid hydrogen cyanide is absorbed in small, thin paper-like discs (Zyklon), each containing almost its own weight of HCN.

Fumigation with hydrocyanic acid gas cannot only be successfully carried out for the disinfestation of empty godowns, but where proper equipments are available, this can be used to disinfest bulk grain also. However, the difficulty is that HCN on account of its lightness does not penetrate to the depth of grain under the ordinary atmospheric pressure.

Carbon bisulphide (CS_2). This is the most commonly used fumigant for the control of store insects in all parts of the world. Its insecticidal value against grain-infesting insects was first discovered in 1858. During the World War II, the use of this fumigant, except in Australia, was less because of short supply.

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Pure carbon bisulphide is a colourless liquid, but the commercial form is slightly yellowish. Similarly, while pure CS_2 is sweet in smell, the commercial form is disagreeable due to the presence of hydrogen sulphide. The liquid readily turns into gas when exposed to air, and is highly inflammable at ordinary temperatures. The liquid should therefore be kept in a cool place and no form of fire should be allowed to come near it. Even a spark produced by a shoe-nail on stone floor, electric switches, etc., may produce explosion when brought into contact with it.

The boiling point of CS_2 is 46·3°C. and specific gravity 1·26. The lower limit of inflammability is 1·06 per cent and the upper is 50 per cent. It is heavier than water--12·6 lb. to one gallon. One pound of the gas occupies about 5 cubic feet of empty space at ordinary atmospheric pressure. The gas is about 2·63 times heavier than air and therefore has a very good penetrating power. It is slightly soluble in water, but it is a good solvent for rubber, gums, waxes, varnishes and oils.

Carbon bisulphide is highly poisonous to all forms of insect life if used at sufficient strength and at 70°F. or above when insects are quite active. Carbon bisulphide vapour is somewhat poisonous to man producing giddiness, nausea, vomiting, coma, and even causing death if breathed in large doses. Those suffering from the weakness of the heart should not handle this fumigant. As regards the preparation of the store for fumigation and general precautions which the operators should take, they are the same as mentioned on p. 61.

As regards application of carbon bisulphide, it can be used by pouring directly on the grain or kept at the top of the bulk in shallow pans. The fumes as they develop out of the liquid will sink down into the bulk. To ensure rapid evaporation, the liquid can be poured directly on rags of cotton placed on the heap of the grain. If the depth of the grain bulk is more than 5 ft., it is advisable to introduce carbon bisulphide below this depth by means of pipes having openings at frequent intervals along their lengths. Grain intended for fumigation should be thoroughly dried before treatment. If it is desired to fumigate grain in bags, they should be stacked in a room or bin which can be closed air-tight. The fumigant should be poured directly over the bags at four corners and over the centre of the stack. The fumigant can be poured in watering cans. This will ensure equal distribution of the fumigant. If, however, the stack occupies only a part of the room it is convenient to cover the stack with a gas-proof tarpaulin. The required quantity of the fumigant may be poured through specially attached leather tubes at convenient points on the tarpaulin. Some space can be provided between the top layer of the bags and the tarpaulin by placing two or three bags edgewise. This space will facilitate the evaporation of the fumigant.

Fumigation of grain under tarpaulin can also be carried out in the open, provided necessary precautions are taken that no form of fire comes any way near the fumigated stack. The grain should remain exposed to the fumigant for 24 to 36 hours depending upon the temperature conditions. The room, as usual, should be opened, aired and the grain exposed to air to remove any trace of the fumigant. Similarly the tarpaulin should be removed from the sides and then from the top and if in the room, it should be opened and proceeded with as mentioned above.

The dosage of carbon bisulphide depends to a very large extent on the gas-absorbing power of the container, although it is mainly calculated on quantity basis. Thirty pounds of the fumigant are generally recommended for nearly 1,000 maunds of grain. It may be necessary to increase the dose where absolute air-tight conditions are not possible.

Carbon bisulphide does not injure the germinating power and palatability of the grain. Any trace of the fumigant can be removed by aeration for a few hours.

Carbon bisulphide mixtures. In order to reduce the fire hazard of CS_2 it is usually mixed four times with carbon tetrachloride. This mixture is in use throughout the United States of America and is now marketed as Grain-O-Cide. The efficacy of such a fumigant would be directly proportional to its carbon bisulphide content. It has been tried and found a very satisfactory fumigant under Indian conditions. It is not advisable for anyone to attempt to manufacture such a mixture as the

safety of the fumigant depends on the way it is prepared. The dose for the 1,000 maunds of grain is about 30 pounds. This gives a satisfactory commercial kill under ordinary conditions.

Carbon tetrachloride. It was first employed as a fumigant for store pests in 1910. During experiments conducted to find a substitute for carbon bisulphide for treating stored grain, carbon tetrachloride was discovered as a grain fumigant. Carbon tetrachloride is a thin, colourless, non-inflammable liquid with a pungent odour. Its boiling point is 76·8°C. (170°F.) and specific gravity 1·595. It slowly evaporates when exposed to air, resulting in the vapours which are not very effective when used alone. It has been estimated that nearly 60 lb. are required to saturate 1,000 c. ft. of space at 77°F. Its chief value lies in mixing with more toxic fumigants, such as, carbon bisulphide and ethylene dichloride, to reduce the fire hazard and with less volatile fumigants, such as, chloropicrin, to hasten vaporization and assist distribution by increasing the volume of the fumigant. It has an anaesthetic effect on man. Although it is not toxic in weak concentrations, care should, however, be taken not to expose oneself to the fumes of carbon tetrachloride alone or any mixture containing this chemical for any extended period of time without wearing gas-masks.

Ethyl acetate. It has considerable merit as a fumigant. A mixture of four parts of ethyl acetate and six parts of carbon tetrachloride produces a safer fumigant than carbon bisulphide. This addition of carbon tetrachloride removes the objectionable odour that is imparted to the grain. Ethyl acetate has a boiling point of 77·1°C. This fumigant is not safely recommended because of the harmful residual effects on the germinating power of the grain.

Ethylene dichloride. This fumigant was discovered as a grain fumigant during the search for a substitute of carbon bisulphide. Ethylene dichloride is a colourless liquid, with an odour resembling that of chloroform. The specific gravity is 1·27, i. e. about 10·4 pounds per gallon. It has a boiling point of 83·7°C. The vapour is approximately 3·5 times as heavy as air, so that on application to grain this will, like carbon bisulphide, have a downward flow. The vapour is inflammable between six to sixteen per cent. It is very slightly soluble in water.

The little fire hazard involved in the use of this fumigant can be overcome by mixing it with carbon tetrachloride in the proportion of three to one. This mixture is non-inflammable and safe to use under all ordinary conditions. Under the present conditions of storage in India, this fumigant mixture is the most suitable. During the past three years this fumigant has become fairly popular for the disinfestation of all kinds of grain. The cost of the fumigant per ton of grain at the dose of one pound a ton is about a rupee. It has no deleterious effect on the grain, even if it is intended for seed purposes, and even if it is moist. The vapours are not toxic to man in ordinary concentrations but it has an anaesthetic action. It is advisable to avoid exposure to the vapour for long periods when without gas masks. The gas being heavier than air can be used for fumigating grain in bulk or in bags and under tarpaulin as described in the case of carbon bisulphide.

Ethylene oxide. It is known as a grain fumigant since 1928. Its use was adopted rapidly because of the ease in its handling and the absence of odour or undesirable residue in the treated material. Ethylene oxide is a colourless liquid at low temperatures, having a boiling point at 10·7°C. (51·2°F.). Its specific gravity is 0·887. At 77°F., nearly 113 pounds of the fumigant are required to saturate the atmosphere of 1,000 c.ft. of space. Because of its low boiling point, it readily evaporates on exposure to air and can, therefore, be applied at a comparatively low temperature. The gas is one and a half times heavier than air. It is generally stored and transported in steel cylinders. It is highly toxic to all stages of insects especially the eggs.

Although ethylene oxide is not toxic to man but when inhaled for a long time, it produces 'cyanosis'. This can be prevented by mixing ethylene oxide with carbon dioxide in the proportion of 1 to 10. Solid carbon dioxide is used for this purpose. This mixture is free from any fire hazard, and does not leave any odour in the treated grain, nor affects the milling and baking quality of the treated grain. It should not be used on grain intended for seed as it reduces germination of the

fumigated grain. The application of this mixture is yet not popular in India, although it is being extensively used in other parts of the world.

The standard dose for tightly sealed bins is 3 pounds per 1,000 c. ft. of empty space. But 3 pounds of ethylene oxide and 30 pounds of carbon dioxide are usually recommended for nearly 1,000 maunds of grain. Both ethylene oxide and carbon dioxide are introduced at the point where the grain enters the bin. An exposure to this gas is needed to bring about a kill in 36 to 48 hours.

Methyl bromide. It is one of the comparatively recent fumigants which is being extensively used. Methyl bromide is believed to be of an exceptional value for fumigating grain [Piper and Davidson, 1938]. It was first used in America in combination with carbon dioxide. The gas has a delayed effect upon insects which is somewhat disconcerting to those using it for the first time. After short exposures under both atmospheric and vacuum fumigation, insects may be seen actively moving about and apparently uninjured when kept in the open air. A few hours later, however, they die because of the effects of the gas.

Methyl bromide is a colourless liquid which boils at 4·5°C. (41·1°F.) and has specific gravity of 1·732. One gallon weighs about 15·5 pounds. At ordinary temperatures, it is a gas which occupies about 4 cubic feet per pound and is about 3 times heavier than air. It is readily volatile but not inflammable. Because of its low boiling point, the fumigant is stored and transported in liquid form in cylinders (10 lb. to 150 lb.) or in small 1 lb. tins. It has a very indistinct smell. Exposure to the gas may result in nausea. Some visional disturbance, headache, loss of appetite and in extreme cases, paralysis of the extremities, delirium may occur which may eventually result in death. It is difficult to perceive the dangerous concentration of methyl bromide but this can be readily detected by the use of what is called Halide leak-detector lamp. If the colour of the flame of this lamp is deeper than a light green, it denotes that the concentration of the gas is unsafe.

Methyl bromide may be applied in several ways for the fumigation of stored cereals. It is usually applied by placing a number of cylinders in a store so as to ensure a uniform distribution of the gas. The fumigant is released from near the ceiling through the copper pipe connected to the exit point of each cylinder. The end of the tube is closed but just below the end there are two small holes so that the liquid is ejected horizontally in opposite directions above the grain stack. The operator must wear a gas mask equipped with canisters. The liquid evaporates as soon as it is released.

Methyl bromide can also be applied from outside through a similar system of pipes. A dose of 1 lb. per 1,000 c. ft. of space surrounded by non-absorbent walls, is reported to give a satisfactory kill. An exposure of 16 to 24 hours should be allowed after which the building should be opened for aeration. At the time of opening the fumigated building the operators must wear gas masks. Ordinarily it may take four to eight hours to give complete aeration.

In India this fumigant has not so far been tried for the control of store pests. It is being tried for the fumigation of fruit infested with Codling moth in Baluchistan.

Chloropicrin. Chloropicrin is one of the war gases which has been adopted for fumigating grain in especially equipped elevators. It has proved useful when used alone or mixed with carbon tetrachloride or trichloroethylene. It is mostly used for fumigation in flour mills.

Chloropicrin is a slightly yellowish liquid, about 1½ times heavier than water, weighing about 17 lb. to a gallon. It has specific gravity of 1·629 and boiling point of 112·4°C. On exposure, the fumigant slowly evaporates forming a mixture with air, which is also about 1·5 times heavier than air at 77°F. and 20·9 in. of atmospheric pressure. Chloropicrin is non-explosive and non-inflammable under ordinary condition and is extremely toxic to insects. It is also toxic to man and is very irritating to the eyes and respiratory passages. Therefore, while using this fumigant the operator must wear gas masks.

Chloropicrin is usually available in cylinders of 1 lb. to 100 lb. capacity. A dosage of 2 lb. per 1,000 md. of grain with an exposure of 48 hours has been found effective. Since vapours of chloropicrin have been found to reduce the germinating power of wheat and other cereals, particularly if the fumi-

gated grain is not properly aerated after the treatment, this fumigant cannot be recommended for grain meant for seed. The baking and milling qualities of the treated grain are also seriously affected.

Trichloroethylene. The utility of this chemical as a fumigant against store insects was established in 1928. It was suggested that this fumigant would prove useful for mixing with more toxic compounds for reducing the fire hazard. Trichloroethylene is a heavy, colourless, non-inflammable liquid boiling at 88°C. and has specific gravity of 1·477. It is similar to carbon tetrachloride in toxicity.

The dosage found effective is $1\frac{1}{2}$ lb. for 1,000 c.ft. of space with an exposure of 48 hours With this concentration the germination of bean seed was not affected [Bouhelier and Foury, 1936], while in another experiment 220 lb. of wheat infested with *Tenebroides mauritanicus* adults and larvae of *Sitophilus oryza* were fumigated with trichloroethylene for 46 hours and it was found that the germination of wheat was affected to some extent.

Methyl formate. Cotton and Roark [1928] investigated fully the use of this fumigant. Methyl formate has a boiling point of 37·8°C. (87·22°F.) with a lower limit of six per cent of inflammability in air and an upper limit of 20 per cent. Commercial mixtures of methyl formate and carbon dioxide are available in the market and are used to some extent in vacuum chambers for the fumigation of cereal products. The most suitable mixture should contain about 15 per cent methyl formate.

Trichloroacetonitrile. This is comparatively a new fumigant. Its toxicity has been tested against various insect pests of stored grain [Bovingdon and Coyne, 1944]. This fumigant is used on a larger scale in warehouses in Germany. Trichloroacetonitrile has a boiling point of 85°C. (185°F.) and is highly volatile. The vapour is nearly five times heavier than air at 25°C. It is non-inflammable and does not affect metals, polish, paints, silks, etc. Additional practical tests are necessary before this fumigant can be recommended for large scale fumigation in India.

Shulphur dioxide. It is one of the oldest known fumigants or disinfectants for infected houses. It was once used for the treatment of flour mills before hydrocyanic acid gas came into use as a fumigant. Sulphur dioxide tarnishes metals, fabrics and paints and has adverse effect on grain and flour. It is generally produced by the burning of sulphur but is also marketed in liquid form in cylinders. It has a boiling point of 10°C. It is non-inflammable at 77°F. Nearly 164 lb. are required to saturate the atmosphere of 1,000 c.ft. of empty space. It is fairly toxic to insects and is very rapid in action but has very little penetrating power. It has got a very irritating effect on the operator even at low concentrations.

Insecticides

Dichloro-diphenyl trichloroethane (DDT). This is one of the recent insecticides which have gained considerable popularity during the recent war. It has proved extensively useful for the control of mosquitoes, flies and other disease-carrying insects in various theatres of war. This chemical was first synthesized by Zeilder [(1874) (*Deut. Chem. Gestell. Ber.* 7, 1180)] by allowing anhydrous chloral and chlorobenzene to react in the presence of concentrated sulphuric acid. It is a colourless, almost an odourless and a fairly stable compound. It is insoluble in water but soluble in most organic solvents. DDT is resistant to strong acids but not to strong alkalies. Solutions of DDT may be corrosive due to traces of sulphuric acid in the product. As a commercial product, it is a whitish, waxy powder which cannot be readily ground. When mixed with an equal weight of talc or gypsum, it may be well-ground to give a very fine powder containing various percentages of DDT.

DDT is primarily a nerve poison acting both as stomach as well as contact poison. Experience has shown that there is no hazard to operators involved in handling the dust. It is directly toxic when dissolved in vegetable oils, in which condition its absorption through the skin is much greater than mineral oils and this may result in serious effects.

In 1945, the use of DDT for the control of stored grain pests was taken up in India. It was tried to disinfest empty godowns by incorporating it in different doses with white-wash, in four per cent kerosene spray, in five per cent dust. The results, show that kerosene spray and dust treatment do hold promise for disinfecting empty godowns. Without further trials no authoritative statement can be made beyond what is stated above.

As regards mixing of small quantities of DDT with the grain as dust, it has decidedly proved effective. But it is being recommended for treating grain meant for seed purposes only, as the question of its toxic effect on the consumers of the grain treated with DDT is yet undecided.

Benzene hexachloride (*BHC*). Benzene hexachloride was first prepared by Michael Faraday in 1825 and its insecticidal value has come into prominence since 1942 as a result of extensive research work carried out in the United Kingdom. This insecticide has properties very similar to dichloro-diphenyl-trichloroethane but benzene hexachloride has more rapid knock-out effect on insects than DDT, but the latter has a better residual effect. Benzene hexachloride has four isomers with different melting points and they are alpha, beta, gamma, and delta. The toxicity of this compound is mostly attributed to gamma isomer which is toxic to insects, whereas alpha and delta are relatively inactive and beta is almost non-toxic. The toxicity of the gamma isomer which forms about 10 per cent of benzene hexachloride is estimated to be nearly 8 to 10 times more than alpha and delta isomers. Benzene hexachloride is a chemically stable compound and is similar in most of its properties to DDT. Like DDT it is also decomposed by alkali and has deleterious effect when mixed with vegetable oils.

Benzene hexachloride is available in the form of dusts, and 'smokes'. Dust is intended for dusting walls, floors, ceilings for disinfestation. Smoke forms are also meant for the disinfestation of empty godowns, which can be made reasonably air-tight. Work on benzene hexachloride in India was taken up simultaneously with DDT and as a result of this it has been recommended that the empty stores can be disinfested with BHC dust at the rate of 6 to 8 oz. per 100 sq. ft. of space as well as by smoke where it is possible to make the rooms air-tight. Mixing of small quantities of BHC dust with grain (one part of three per cent dust to 10,000 parts of grain) keeps it free from store pests. As in the case of DDT this treatment is still being given to seeds only, as the question of toxicity of this insecticide to human beings is also yet not decided.

Other methods

(*a*) *Superheating*

Store insects are killed in all stages of their life if exposed for several hours to a temperature between 125° F.and 135°F. Exposure to such temperatures for not more than five or six hours does not injure the germinating power of seeds. Above this temperature, however, there is danger of injury. Large quantities of grain are best treated by passing them through machines. Such machines, if properly constructed, will raise the temperature of grain passing through them to a point sufficiently high to kill insects in all stages. But it is difficult to get even distribution of temperature in large bins of grain, the temperature becoming too high in the outer layers of the grain before it reaches a sufficiently high level in the middle of the bin to prove lethal to insect life.

In Garmany, an exposure of even one hour to 116°F. is known to have killed all stages of *Calandra granaria* L. without impairing the germination of wheat [Zacher, 1935]. It was also found that adult stages of almost all pests when exposed to 55°C. (131°F.) died in 30 minutes.

Sunning the grain once or twice in a year for reducing insect attack is a common practice with the cultivators. They usually spread out the grain so as to expose them to the heat of the sun for about six hours; the grain is turned or shovelled at intervals to ensure uniform exposure to heat. The cultivator generally exposes his stored grain towards the end of September, a month after the summer rains, when there is a great likelihood of the grain insects multiplying in quick succession.

(b) *Refrigeration*

The effectiveness of cold in protecting beans, peas, and cowpeas against weevil attack has long been recognized, and is practised in other countries but it appears that relatively little attention has been paid to the proper development of the process.

(c) *Use of vacuum*

The use of vacuum for the control of insects has not received much attention so far by the commercial world. This is as yet only in an experimental stage, but it promises a good method of control for these insects wherever facilities are available. For experimental details the reader is referred to a paper by Back and Cotton [1925] on this subject.

(d) *Trapping*

For *Sitotroga cerealella*, trapping has been tried and recommended in Germany. Large numbers of moths are trapped in trays half full of water on which cocoanut oil has been poured. These traps can be effective if the store is in darkness [Fleuren, 1922]. In India, this method has been employed in Bombay with great success. Large number of moths and beetles were found trapped in heavily infested godowns thereby considerably reducing the infestation.

(e) *Sticky bands*

Use of sticky substances in a band similar to those used for banding trees to the walls or floors of storage buildings is also recommended. These substances may partially control or may restrict movements of several store insects. These bands are of use in isolating infested piles of goods in which case they may be applied to the floor. Care should be taken to ensure that the sticky surface is free from any dust and is in a fresh condition.

(f) *Emulsions*

In certain parts of the world spraying of infested grains with oil emulsions has given satisfactory results. One part of a suitable fat, when mixed with four parts of 1 per cent soap solution, produces a stable emulsion that causes 100 per cent mortality to *Sitophilus granaria*.

Some oil emulsions and miscible oils used for spraying fruit trees have been found to protect stored maize from insect attack without affecting the germination of the grain.

The stock lubricating oil emulsion is prepared by boiling together for about five minutes one quart water, 1 lb. to 2 lb. potassium oleate (quantity depending upon the hardness of water) and one gallon light grade lubricating oil. This is said to have been tested against *Sitotroga cerealella, Sitophilus oryza, Tribolium confusum* and *Oryzaephilus surinamensis* [Flint and Mohr, 1930]. The grain is placed in baskets or preferably slated crates; these are dipped in a tub or small tank containing the liquid and then removed immediately and placed on a draining board to permit the excess liquid to run back to the tank. The grain is thoroughly dried and stored with as little handling as possible, as it is apparently the thin film of oil surrounding each seed that protects it from insect injury. Such methods of treating grain have been attempted but not developed in India for large scale treatments.

(v) Control of insects in transport

Insect infestation develops frequently while grain and milled products are being transported from one place to another. It has often been found that clean grain becomes infested when carried in infested bags, trucks, railway wagons or ships. Conversely, infested grain may infest any of the above means of transportation if it is clean. The insects are ultimately carried with the stuff into the store which in turn becomes infested with insects. It is, therefore, essential that proper attention is regularly paid to the disinfestation and keeping of the transport equipments clean.

Used bags. Disinfestation of used bags can be accomplished by fumigating with ethylene dichloride/carbon tetrachloride mixture. The dose recommended is 30 lb. for about, 1,500 bags, or 1,000 c. ft. of space.

Trucks. It should be made a routine practice to thoroughly clean daily all the trucks used for carrying grain and grain products. Electric vacuum cleaners will give much better results than ordinary brooms and brushes in places where there is electricity.

Railway wagons. Cleaning with vacuum cleaners or compressed air will go a long way to clean the wagons at a nominal cost.

Spraying with DDT and BHC wettable products is very effective against store insects. This treatment should be given at regular intervals or before loading. Fumigation and smoke treatments would be ideal but their effectiveness will be largely dependent on the possibility of making the wagon air-tight.

Ships. Insect infestation in ships can be best controlled by fumigation or contact sprays. Fumigation with hydrogen cyanide is usually carried out with successful results. The dose recommended is nearly 8 oz. per 1,000 c. ft. Contact sprays containing pyrethrum extracts (0·8 per cent of total pyrethrin) have also been reported to give satisfactory kill of insects on ships.

(vi) Control of termites

Against termites which infest and damage store buildings, floors, walls or the ceilings, the affected parts can be protected by the use of zinc chloride or sodium arsenite. The floor before plastering should be well-watered so as to make the earth damp up to a depth of three inches. After the water has been absorbed the second watering with 20 per cent solution of zinc chloride or 3 per cent solution of sodium arsenite should be given. The average penetration of this insecticide should be up to the depth of one to two inches. These remedies are very expensive. In order to obtain a cheaper solution of sodium arsenite, 1 lb. of crude arsenic and 3 lb. of washing soda should be boiled in 8 gallons of water which should be diluted up to 24 gallons. This stock solution will be enough for 100 sq. ft. The repair of settlement or construction-joint should be done with first quality cement after these treatments have been given. Coal-tar pitch and other aliphatic compounds have also been found useful in preventing the access of termites through cracks and crevices in store buildings.

Termites can be temporarily controlled by following back the earthen tracks to the point of their entry into the building. The holes at that point or any opening at that point should be widened out and any of the following poisons may be dusted in : Paris green, white arsenic, sodium fluosilicate or creosote. It may be mentioned that arsenates are quicker in action than fluorine compounds. This will prevent the development of the colony or it will help desertion of the colony from the point near the affected building.

If the damage occurs in damp buildings due to leakage of water, the drainage should be improved, leaks repaired, ventilation provided to ensure complete relief from termites.

So long as chances of re-infestation of superstructure exist by the arrival of fresh lots of worker termites from the ground or by the formation of new colonies the remedies stated above will not

eradicate the pest. It is, therefore, essential that frequent inspection of all store buildings should be maintained at regular intervals particularly during rainy periods when fresh colonies are expected to be built.

The important measures which must be applied for the prevention of damage to structures made wholly or partly of wood are :

(i) Elimination or prevention of breeding and colonization of termites in the vicinity of any store building.

(ii) Making the structure inaccessible to termites by means of barriers formed by special constructional designs.

(iii) Use of resistant timber or that treated with proper preservatives.

(iv) Sites for stores should be at such places where in the neighbourhood, there are no termite nests underground or above-ground.

(v) Decaying logs or leaves, stumps or buried roots in the vicinity of the stores should be removed and destroyed. This material will show the presence of underground termites.

(vi) In the case of mounds-building termites, the mounds can be broken from the top and the galaries exposed and any one of the following insecticides poured to kill the queen inside the nest :

(*a*) White arsenic at the rate of $\frac{1}{4}$ oz. to $\frac{1}{2}$ oz. for a mound about a foot high. It is better to mix the powder with fine dust or sand. After treatment the surface should be covered with a layer of soil and levelled off.

(*b*) A mixture of creosote with three parts of kerosene oil or petrol.

(*c*) Carbon bisulphide pure or emulsion.

(*d*) Ethylene dichloride, carbon tetrachloride mixture.

(*e*) Para-dichloro-benzene.

(*f*) Petrol.

When termites do not build conspicuous mounds but inhabit diffuse nests and tunnels underground it is not possible to destroy their nests extensively unless exit-holes are located when swarming occurs. The only possibility in such cases is drenching the foundation soil with zinc chloride or sodium arsenite poisonous solutions. But such soil treatment provides only a temporary benefit and it is advisable to protect the walls and woodwork against termites by providing proper barriers. It is possible that after the building has been built fresh pests may appear in the locality. Adequate drainage of the site and good ventilation will be of great help.

Buildings with earth or cowdung floors or mud walls, walls of sun-dried bricks or burnt brick in mud mortar, walls of stone in mud mortar, and walls of untreated wattle or bamboo matting cannot be made termite-proof.

The buildings that are capable of being made termite-proof are those having concrete floors in contact with the ground and those having floors raised above-ground, by masonry pillars. Conduit or plumbing pipes should be so arranged so as to prevent termite from gaining access to the building by building their runways alongside the pipes. Pipes passing through concrete should so fit that not even a minute opening is left between the pipe and the concrete. Metal sheets round the pipes passing through the ground will provide adequate protection against termite.

Complete isolation from the ground of all untreated woodwork of buildings is the only effective way against sub-terranean termites.

(vii) Control of rats

The rat control methods generally resolve themselves into four categories : (*a*) Rat-proofing of stores and buildings, (*b*) fumigation of rat burrows, (*c*) poison baiting, and (*d*) trapping.

(a) *Rat-proofing of stores and buildings*

(i) All floors should be of concrete or stones covered over with concrete plaster. Foundations should be about three feet deep and have concrete filling. Walls should also be of brick in lime or concrete or stone and similarly the ceiling if possible as *Rattus rattus* sometimes make nests in the ceiling.

(ii) Doors when shut should leave no gaps. Thresholds should be built up hardened with granolithic so that doors remain tight fitting. Tin plates should be fitted along the bottom six inches of the doors, passing the lower end of the tin plate below the door to the other side and nailed. This will prevent rats gnawing the door to effect entry into the stores. Sliding doors should be proofed against rats with a substantial metal plate, 6 ft. high covering the entire edge of the door and the gap and should be turned round at right angles to lie on the fixed door or the adjoining panel. Gap between the meeting edges of the doors, when shut, should be covered to a height of about 3 feet with a flat metal plate bolted to one of the doors when closed.

(iii) Window openings should be about three feet above the ground level and the walls at the base of windows should be perfectly smooth. In the absence of this, the windows should be fitted with a 9 in. wide horizontal tin plate or wire netting.

(iv) Drain pipes should be cut 3 in. from the ground level or the lower opening should be fitted with a wire netting of any expanded metal. Any such hole that may facilitate entry of rats into the store should be similarly fitted with wire netting.

(v) Any rat-hole observed inside a store should be sealed filling with cement containing pieces of broken glass. In soft floor this is not possible. Rat-proofing of the building as suggested above should be completed before the grain leaves threshing floor.

(b) *Fumigation of rat burrows*

Rats can be killed by introducing into their burrows any poisonous gas. Cyanogas and cyamag described in previous pages which give out HCN have been found to be the best fumigants. The fumigant can be introduced into the burrows by means of spoons and by foot-pumps, and the holes blocked and sealed with mud.

Precautions should be taken while handling cyanogas, as in the case of all fumigants containing hydrogen cyanide.

(c) *Poison baiting*

This treatment requires a baiting base and a poison. The most promising raticides are alphanapthylthiourea, zinc phosphide, arsenic (arsenious oxide), barium carbonate and strychnine. The most common bait bases are : (i) dry crumbs of bread, (ii) ground biscuits, (iii) boiled grain of wheat, 'jowar', gram, etc. or (iv) boiled rice for 'wet' baits and (v) wheat or gram flour, 'atta' with sugar for dry baits.

Alpha-napthyl-thi ourea popularly called 'Antu' is gaining popularity in America where it is being manufactured in large quantities. Tests carried out in India against *Rattus* have shown that this poison is effective and easy of application. Five parts of the poison with 95 parts of wheat flour as a dry bait have given very promising results.

Zinc phosphide is a rat-poison recently introduced in India. The only difficulty is that this poison cannot be used in wet baits without taking certain precautions because with water it gives

off traces of fluorine gas. Dry bait of zinc phosphide with the whole wheat grain (1:9) and a trace of vegetable oil will form a stable bait which can keep well for long periods of time. Arsenious oxide is used as a dry bait at the rate of 3 to 17 parts and wet bait at the rate of 2 to 18 parts. Barium carbonate is used in the ratio of 1 : 4. One ounce of strychnine chloride is mixed with 30 lb. of grain and some sweetening material such as 'gur'. All the raticides named above are very poisonous and should be handled with extreme care. Hands utensils should be thoroughly washed after preparation of baits. The residues should be buried.

It may be pointed out that at least two other alternative poisons should be available always as it is not safe to depend upon any one poison.

In order to prevent the rats from suspecting that any campaign is being carried against them it is necessary to first apply unpoisoned bait. This method is called 'prebaiting'. After the rats have gained confidence, the unpoisoned bait should be mixed with the poison selected. After a break of about two weeks place another poison bait and if the rats are still there, they will be killed by the second bait laid subsequently. Break the treatment for another week or so to create confidence in rats, repeat baiting with the two poisons again.

If baiting is properly carried out in a well-planned manner over a large area, about 90 per cent kill of rats can be expected even with the first treatment.

Where there is danger to human beings, animals or birds, 'prebaits' and poison baits must be placed in small boxes or pipes. Whatever containers are used they should be placed along the tracks of the rats and should be determined before undertaking this treatment.

(d) *Trapping*

There is a variety of traps marketed in India for catching rats. The most common are the 'cage trap' the 'break-back treadle' trap and the 'break-back' trap.

The first two are useful for trapping rats and the third is useful for mice. Standard cage traps have been designed by the Director, Haffkine Institute, Bombay and are u ed in large numbers in the Presidency. The break-back treadle trap is not good for large infestations which are best tackled by poison baiting. The break-back traps are the best for dealing with mice. It is, of course, necessary to use a fairly large number of traps (20 to 50) at a time.

The traps should be placed at the exit point of holes or at right angles across the runways. Only one trap should be set, duly baited, with any suitable material such as bread, crust, fruit or fish. When rats start visiting the trap, set more traps at once. Traps should be examined daily until no rat is trapped.

V. GENERAL RECOMMENDATIONS

Storage receptacles

(i) For bulk storage cement concrete 'khattis' (whether underground or above-ground) or bins are ideal structures. Next in order of merit are the ones built of brick with cement concrete plaster on inside walls and floors.

(ii) For bag storage, 'pucca' cement concrete or brick stores with complete facilities for fumigation will be most satisfactory.

Storing grains in bulk is more satisfactory than in bags which is the common method in use. For bulk storage of grain, underground or above-ground, rectangular or circular bins made of cement concrete are the most satisfactory structures. Where it is not possible to have them built of cement concrete, 'pucca' masonry structures with well plastered walls, floors and ceilings finished with a coating of waterproof material will be equally suitable.

Among the existing indigenous methods of storage, receptacles made of straw are the best for short term storage of grain in bulk.

Where the grain has to be stored in bags, it is essential to keep them in 'pucca' stores with walls, floor and ceiling properly plastered as far as possible to a smooth finish. Doors, windows and ventilators should be tight fitting and open outside. In areas of high humidity walls should have an additional coating of water-proof material.

Hygiene and maintenance of godowns

(i) Before use the store should be cleaned of all rubbish. The sweepings should be collected and burnt. If necessary it should be disinfested with any of the methods described in Chapter IV, p. 51.

(ii) All cracks and crevices on walls, floors and ceilings should be filled in with cement and levelled. All loose plasters should be scrapped off and replaced.

(iii) Any large holes which are usually made by rats should be filled in with sand mixed with pieces of glass and levelled up. It should be ensured that the doors are rat-proof. Methods of rat-proofing have been described in the previous chapter under head (vii) dealing with the 'control of rats'.

It should also be ensured that the grain before storage is dry, uninfested and clean. If the grain is infested it should be screened or fumigated with a suitable fumigant as described in Chapter IV. Damp and wet bags should be opened and grain dried and rebagged in clean bags.

Bags should be properly stacked up to a suitable height depending upon the height of the godown. As a general rule, about 20 per cent of the space between the top layer of the stack and ceiling should be allowed. Stacks should be separated from the wall and from one another by an alleyway of 1½-2 ft. to allow for ventilation and proper inspection.

Proper dunnage should be provided below each stack so that the bags are kept off the floor. Timber battens are the best dunnage material ; if these are not available loose bricks or ballies may be used.

ure of grain during storage

Grain should be frequently inspected at least once a month and during rains once a fortnight. nall patches of powdery material indicate heavy infestation. If none is obvious on the outer bags, few bags on the top should be turned and the next layer examined. If any heating or heavy instation in the bags is discovered the stocks should be turned over and fumigated and disposed off the earliest opportunity. The remaining stocks should be given particular attention as it is always ble to infestation. The same precautions are to be taken if 'heating' of the stored grain is scovered. Temperature above 80°F. and with excessive moisture in the store are factors indicatg 'heating' in the grain.

The stores should be daily swept clean of all rubbish, webbings and dirt.

Stores should be kept properly ventilated. During rains ventilators should be kept closed pening on dry days only.

eneral

Bags, trucks, railway wagons, ship-holds, boats used in the transport of grains should be kept ean. Insects are usually found in the accumulated grain remnants in crevices between the footoards, etc., of such vehicles and in meshes and seams of the bags. They should be treated with suitable migants or insecticides as described in Chapter IV.

APPENDIX

List of Important Storage Pests

A. COLEOPTERA

Curculionidae

Sitophilus oryza Linnœus

Sitophilus granaria Linnœus

Bostrychidae

Rhizopertha dominica Fabricius

Trogostidae

Tenebroides muritanicus Linnœus

Tenebrionidae

Tribolium castaneum Herbst

Tribolium confusum Jacq. Du Val.

Tenebrio molitor Linnœus

Latheticus oryzae Waterhouse

Alphitobius piceous Olivier

Cucujidae

Oryzaephilus surinamensis Linnœus

Laemophleus minutus Olivier

Ptinidae

Gibbium pysylloides Fabricius

Dermestidae

Trogoderma granaria Everts

Attagenus piceus Olivier

Bruchidae

Pachymerus (=*Bruchus*) *chinensis* Linnœus

Pachymerus (=*Bruchus*) *quadrimaculatus* Fabricius

Bruchus analis Fabricius

Bruchus albocallosus Picot

Bruchus phaseoli Gyllenhab

Laria (=*Bruchus*) *affinis* Froel

Laria (=*Bruchus*) *emarginatus* Allard

Laria (=*Bruchus*) *pisorum* Linnœus

B. LEPIDOPTERA

Pyralidae

Corcyra cephalonica Stainton

Pyralis farinalis Linnœus

Phycitidoe

Ephestia cautella Walker

Plodia interpunctella Hubener

Gelechiidae

Sitotroga cerealella Olivier

C. ORTHOPTERA

Blattidae

Periplaneta americana Linnœus

Periplaneta australasiae Fabricius

Blatta orientalis Linnœus

Blatta germanica Linnœus

Stylopyga rhombifolia Stall

Gryllidae

Gryllulus domesticus Linnœus

Gryllus sigillatus Walker

D. HYMENOPTERA

Formicidae

Dorylus labiatus Shuck

Monomoricum indicum Forel.

Camponotus compressus Fabricius.

E. THYSANURA

Lepismidae

Lepisma saccharina Linnœus

F. PSOCOPTERA

Psocidae

Liposcelis transvallensis Enderlein

Liposcelis divinatorius Muell

G. ISOPTERA

Termites

H. ARACHNIDA

Tyroglyphidae

I. RATS

J. FUNGI

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